

Article

Comprehensive Evaluation of Storage Performance of the Yellow-Fleshed ‘Jinyan’ Kiwifruit Harvested at Different Maturities

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Abstract

‘Jinyan’ is an interspecific hybrid kiwifruit (*Actinidia eriantha* × *A. chinensis*). It is a large, yellow-fleshed fruit with good taste and long storage potential. It is commonly referenced that storage potential is linked to the harvest maturity of the fruit and the subsequent temperature management. Hence, the findings from research covering the maturation, storage temperatures, ripening, and quality of ‘Jinyan’ fruit from the same orchard across three seasons have been evaluated with an overall objective of defining harvest and storage criteria for ‘Jinyan’ fruit. Good postharvest performance includes fruit not becoming too soft too soon in storage and retaining firmness at shelf temperatures. It was confirmed that harvest maturity is critical to the good storage performance of ‘Jinyan’ kiwifruit. Harvest time significantly affected fruit softening during cold storage, and treatment with the ethylene action inhibitor 1-methylcyclopropene slightly delayed fruit softening. Harvesting much before 180 days after full bloom, or at <9% soluble solids content (SSC), resulted in high incidences of chilling injury (41.8–52.0% after 24 weeks of cold storage at 1 °C + 7 d at 20 °C). These chill-damaged, early-harvested fruits also had a high incidence of rot. Leaving the fruit on the vine much after this threshold reduced chilling injury, but increased the risk of rot on otherwise sound fruit (total rot incidence ranging from 25.9% to 89.0% depending on maturity at harvest). As well as chilling risk, early-harvested fruit may reduce the consumer’s liking of the fruit because of a reduced ripe fruit SSC (rSSC). Consumer liking may also be reduced for long-stored fruit in years of low fruit dry matter content. The impact of low rSSC on consumer liking and the presence of any threshold values requires confirmation. These findings define a clear indication of when fruit should be harvested for long storage, whilst minimizing the risk of disorders.

Keywords: *Actinidia*; maturity; storage; temperature; ethylene; 1-MCP; quality



Academic Editor: Elazar Fallik

Received: 29 May 2026

Revised: 23 June 2026

Accepted: 25 June 2026

Published: 26 June 2026

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1. Introduction

Kiwifruits (*Actinidia* spp.) are economically and nutritionally important fruits that are commercially harvested when mature but firm and unripe, so that they may be stored for up to several months at low temperature to prolong their marketing period [1]. It has been well documented that the physiological state of the fruit at harvest, commonly referred to simply as its maturity, combined with the postharvest management applied,

determines the storage performance of the fruit [1,2]. Storage performance includes the maintenance of fruit firmness and keeping the fruit free from physiological disorders and rot. Beyond being free from defects, the inherent consumer liking of kiwifruit is largely based on the ripe fruit soluble solids concentration (rSSC), which can be estimated from an at-harvest measurement of dry matter (DM) [3,4]. Thus, it is essential to understand the physiological development and composition of any kiwifruit cultivar to determine the optimal postharvest management to provide consumer satisfaction.

Fruit growth and development are affected by both the cultivar genetics and the growing environment. In general terms, the progression of kiwifruit development can be observed as the change in SSC. However, this is a compositional measure and may be affected by the environment, particularly with cold temperatures inducing starch breakdown, elevating the SSC [2], and vine management, including the use of plant growth regulators [5,6] and girdling [7]. Cool temperatures can also induce fruit softening [8–10]. While DM may be mentioned in terms of maturity, it is only useful for maturation if monitored to see the point at which carbohydrate accumulation ceases [2]; otherwise, it simply provides an at-harvest estimation of the quality parameter rSSC [11,12]. However, there are some elements of maturation that are not simply compositional. These include the change to dark seeds, the cessation of growth, and the change to ripening (rapid softening and starch loss) [2]. One key element for yellow-fleshed kiwifruit is the loss of chlorophyll, which is necessary to reveal the underlying yellow pigmentation [13,14]. This process of degreening has, in those cultivars examined to date, been shown to be temperature sensitive, occurring very slowly, or not at all, below $\sim 5^{\circ}\text{C}$ [15].

Fruit softening and disorder incidence are the two most commonly reported fruit quality attributes used to describe storage performance [1]. Most commercial situations focus on maintaining firmness in storage for as long as possible to extend the marketing window. Harvest time affects fruit softening in cold storage, as it determines where in the natural softening pattern the fruit is when harvested, thereby influencing subsequent softening during storage. The kiwifruit softening pattern is sigmoidal, with three distinct phases: Phase 1 slow, Phase 2 fast, and Phase 3 slow [16]. The specific rates of softening in each phase differ among cultivars [10], and how clearly these phases are seen in storage largely depends on the harvest maturity and frequency of measurement. Generally, it takes a longer time for early-harvested kiwifruit to soften to eating firmness ($<10\text{ N}$, measured with a 7.9 mm diameter penetrometer), while fruit harvested later may already be in Phase 2 fast softening at harvest [17,18]. Contrasting reports that late-harvested fruits were firmer than early-harvested fruits after cold storage [19,20] may also depend on when the fruit was assessed and the condition of the fruit. Early-harvested fruit often shows an excessive softening in Phase 3 compared with more mature fruit, possibly associated with chilling damage.

Kiwifruits do not produce large amounts of ethylene until they are eating-ripe [21–23]. Hence, most of the ripening occurs in the absence of a large production of ethylene, yet the ethylene action inhibitor 1-methylcyclopropene (1-MCP) has been shown to slow softening slightly [24,25], albeit not to the extent seen in some apple cultivars [26,27]. This suggests that despite the lack of natural ethylene production during ripening, ethylene does play some minor role in the control of fruit softening. However, with kiwifruit being very sensitive to low concentrations of ethylene [28,29], 1-MCP is particularly effective in protecting kiwifruit from exogenous sources of ethylene [30], an effect that may last for weeks after the initial treatment [25].

While most references to fruit firmness are based on measurement of the outer pericarp, a lack of softening of the fruit core will detract from the eating quality of the fruit if the core is noticeably firmer than the pericarp [31]. While the etiology of this disorder has been

ascribed to the use of controlled atmosphere storage [32–34] or 1-MCP [34,35], the issue seems to be associated with the use of low-maturity fruit [36,37] and being dependent on genotype [38].

In addition to fruit softening, fruit quality loss during storage may be associated with rot and chilling damage. Rot is often dependent on the growing location and postharvest handling and temperature management [39]. Fruit of all kiwifruit cultivars are susceptible to chilling damage at temperatures close to 0 °C, with susceptibility being mostly associated with low-maturity fruit stored for too long at low temperature [1]. Fruit with chilling damage is highly susceptible to opportunistic rot [40].

‘Jinyan’ is an interspecific hybrid (*A. eriantha* × *A. chinensis*) with large, yellow-fleshed fruit of good taste and long storage potential [41,42]. It is a late-maturing cultivar that is commonly harvested at the end of October in the Wuhan region of China [42]. Currently, it is the most widely commercially planted yellow-fleshed kiwifruit cultivar in China [43] and is also grown elsewhere in the world.

While there is published work on individual aspects of maturity effects on quality and storage, fruit growth, and aroma components at different maturity stages of ‘Jinyan’ fruit [44–47], these studies were limited to single seasons, and the linkages and interactions among these aspects were not fully explored. Since seasonal variation can influence fruit maturation and storage behavior [2], a multi-season study from the same orchard is essential to generate reliable recommendations. Hence, the findings from research covering the maturation, storage temperatures, ripening, and fruit quality of ‘Jinyan’ fruit from the same orchard across three seasons have been comprehensively evaluated with an overall objective of defining harvest and storage criteria for ‘Jinyan’ fruit.

2. Materials and Methods

2.1. Fruit

‘Jinyan’ (*A. eriantha* × *A. chinensis*) fruit used for this study was grown in a commercially managed orchard at Danjiangkou City (DJK), Hubei province, China. The vines were trained on a pergola system, which is the standard commercial practice for this cultivar in the main region of China. ‘Jinyan’ scions were grafted onto ‘Miliang No.1’ rootstocks (*A. chinensis* var. *deliciosa*) in 2017. All fruit was taken randomly from the designated vines, with only sound fruit being used.

2.2. Trial Designs

2.2.1. Fruit Growth and Maturation Trial

‘Jinyan’ fruits were obtained from the same ~15 vines in a single orchard at DJK in 2021, 2022, and 2023. Fruit maturity was monitored at intervals of 1–2 weeks between 22 May (14 days after full bloom, DAFB) and 18 November (194 DAFB) in 2021 (21 DAFB) and 9 November (196 DAFB) in 2022, and 17 May (21 DAFB) and 29 November (216 DAFB) in 2023. The temperature and precipitation data for the three seasons are given in Figure 1, illustrating a period of high temperatures with some daily maximum temperatures >40 °C, and low rainfall during the period June–August 2022. At each harvest, 20 sound fruits were randomly harvested from the designated ~15 vines and transported to the laboratory of Wuhan Botanical Garden, Chinese Academy of Sciences (WBG, CAS, located in Wuhan City) at ambient temperature, arriving within 24 h of harvest. Fruit weight, seed color, flesh firmness, flesh color, SSC, and DM were measured immediately on arrival.

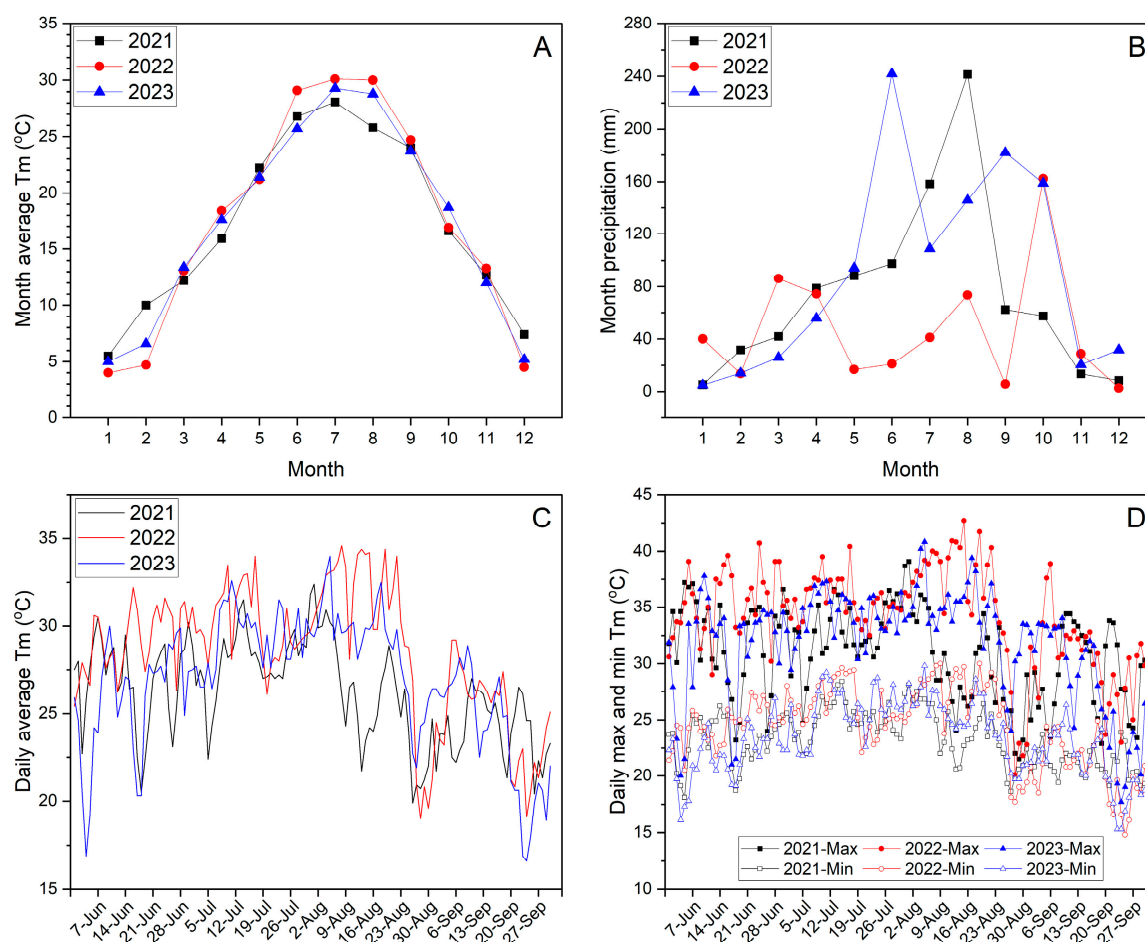


Figure 1. Monthly average temperature (A) and precipitation (B), daily average temperature (C), and daily maximum and minimum temperature (D) for June–September 2021, 2022, and 2023 in Danjiangkou City, Hubei, China. The raw data were downloaded from the China Meteorological Administration (<https://data.cma.cn/>).

2.2.2. Storage Trials

‘Jinyan’ fruits for the storage trials were harvested from the same orchard block as the maturation trial (which used ~15 designated vines), but from approximately 80 vines within that block to provide sufficient fruit for the storage experiments. Fruits were randomly sampled across these vines and transported to WBG, CAS at ambient temperature in 18 L plastic crates, arriving within 24 h of harvest. The harvests were for similar dates as described for the maturation trial. Over the period 2021–2023, several trials were conducted each year: maturity and storage and response to 1-MCP in 2021; maturity and storage, storage temperature, and ethylene ripening in 2022; maturity and storage in 2023.

Maturity and Storage Trial

‘Jinyan’ fruit for long-term cold storage at 1 °C were harvested at five different maturities in the 2021–2023 seasons (H1 to H5, corresponding to 166 to 194 DAFB in 2021; H1 to H5, 165 to 196 DAFB in 2022, and H1 to H7, 166 to 209 DAFB in 2023, Table 1). Fruits were transferred to WBG CAS on the day of harvest.

Table 1. At-harvest characterization of ‘Jinyan’ kiwifruit harvested at different times in 2021–2023. Values are means $\pm$ sem, $n = 20$. Values within a column for a single year not sharing a common letter differ at $p = 0.05$ by Tukey test.

Year	Harvest	DAFB ^x	Harvest Date	Fresh Weight (g)	Flesh Firmness (N)	Flesh Color (°h)	SSC ^y (%)	Dry Matter (%)
2021	H1	166	21 October 2021	122.1 $\pm$ 5.01 ^a	55.0 $\pm$ 2.54 ^a	101.4 $\pm$ 0.41 ^{ab}	8.5 $\pm$ 0.34 ^c	15.9 $\pm$ 0.21 ^b
	H2	173	28 October 2021	110.4 $\pm$ 3.97 ^{ab}	46.0 $\pm$ 3.73 ^{ab}	100.5 $\pm$ 0.44 ^{ab}	9.7 $\pm$ 0.31 ^{bc}	15.9 $\pm$ 0.15 ^b
	H3	180	4 November 2021	116.7 $\pm$ 2.79 ^{ab}	34.4 $\pm$ 3.44 ^{bc}	100.0 $\pm$ 0.35 ^b	10.1 $\pm$ 0.29 ^b	16.5 $\pm$ 0.16 ^{ab}
	H4	187	11 November 2021	105.2 $\pm$ 2.83 ^b	36.3 $\pm$ 3.10 ^{bc}	102.2 $\pm$ 0.47 ^a	11.4 $\pm$ 0.38 ^a	16.8 $\pm$ 0.16 ^a
	H5	194	18 November 2021	112.6 $\pm$ 3.31 ^{ab}	32.3 $\pm$ 3.27 ^c	101.4 $\pm$ 0.40 ^{ab}	12.4 $\pm$ 0.28 ^a	16.9 $\pm$ 0.17 ^a
2022	H1	165	9 October 2022	104.8 $\pm$ 2.10 ^a	77.4 $\pm$ 1.64 ^a	102.1 $\pm$ 0.34 ^a	8.1 $\pm$ 0.15 ^d	17.7 $\pm$ 0.17 ^a
	H2	174	18 October 2022	98.5 $\pm$ 3.26 ^{ab}	64.4 $\pm$ 2.35 ^b	100.3 $\pm$ 0.25 ^b	10.2 $\pm$ 0.18 ^c	18.2 $\pm$ 0.15 ^a
	H3	182	26 October 2022	95.4 $\pm$ 2.86 ^{ab}	55.2 $\pm$ 3.70 ^b	100.0 $\pm$ 0.37 ^{bc}	10.2 $\pm$ 0.24 ^c	17.7 $\pm$ 0.22 ^a
	H4	189	2 November 2022	89.8 $\pm$ 3.37 ^b	33.8 $\pm$ 2.77 ^c	98.8 $\pm$ 0.26 ^{cd}	11.8 $\pm$ 0.26 ^b	17.9 $\pm$ 0.14 ^a
	H5	196	9 November 2022	92.0 $\pm$ 2.81 ^b	20.0 $\pm$ 1.59 ^d	98.0 $\pm$ 0.38 ^d	13.2 $\pm$ 0.30 ^a	18.3 $\pm$ 0.22 ^a
2023	H1	166	10 October 2023	125.3 $\pm$ 3.23 ^{bc}	61.0 $\pm$ 1.74 ^a	102.8 $\pm$ 0.44 ^a	6.6 $\pm$ 0.22 ^d	15.7 $\pm$ 0.21 ^b
	H2	173	17 October 2023	115.4 $\pm$ 2.08 ^c	53.9 $\pm$ 2.79 ^a	100.0 $\pm$ 0.34 ^b	8.1 $\pm$ 0.26 ^c	16.2 $\pm$ 0.17 ^{ab}
	H3	181	25 October 2023	125.5 $\pm$ 2.08 ^{bc}	53.6 $\pm$ 2.04 ^a	100.4 $\pm$ 0.31 ^b	8.4 $\pm$ 0.20 ^c	16.4 $\pm$ 0.14 ^a
	H4	188	1 November 2023	130.8 $\pm$ 3.28 ^{bc}	43.1 $\pm$ 2.51 ^b	100.5 $\pm$ 0.24 ^b	9.5 $\pm$ 0.24 ^b	16.7 $\pm$ 0.29 ^a
	H5	195	8 November 2023	135.1 $\pm$ 5.43 ^{ab}	42.8 $\pm$ 2.26 ^b	99.7 $\pm$ 0.23 ^b	10.3 $\pm$ 0.18 ^b	16.4 $\pm$ 0.12 ^{ab}
	H6	202	15 November 2023	149.4 $\pm$ 4.44 ^a	36.3 $\pm$ 2.94 ^b	99.4 $\pm$ 0.15 ^b	10.3 $\pm$ 0.21 ^b	16.7 $\pm$ 0.11 ^a
	H7	209	22 November 2023	129.6 $\pm$ 3.69 ^{bc}	26.1 $\pm$ 2.39 ^c	99.7 $\pm$ 0.20 ^b	11.2 $\pm$ 0.23 ^a	16.8 $\pm$ 0.15 ^a

^x days after full bloom, ^y soluble solids content.

On arrival at WBG CAS, 20 fruits from each harvest were collected randomly across all boxes for measurement of fruit maturity. The remaining fruits were packed into six 30 L plastic crates (~100 fruit/crate) with perforated polyethylene bags to maintain high relative air humidity (>95%) around the fruits, and then divided into two lots of three crates each. One lot was for firmness monitoring during cold storage; the other lot was for storage disorder evaluation at the end of storage. The crates of fruit were transferred to a cold room at 1 °C and stored for up to 24 weeks (2021 and 2023) or 32 weeks (2022). The cold room was not equipped with an ethylene filter but had a timed ventilation system for regular air exchange. At intervals of 1 to 4 weeks of storage, 20 fruits were sampled from the three crates identified for firmness monitoring and measured immediately for fruit flesh firmness and core firmness. Fruits in the other three crates were assessed for storage disorders at the end of storage and after a further 7 days at 20 °C.

At each sampling time point (16 weeks of storage in 2021, 20 weeks in 2022, and 24 weeks in 2023), fruits were warmed overnight to 20 °C and then measured individually for fruit firmness and rSSC ($n = 20$ in 2021 and 2022; $n = 30$ in 2023). The peeled flesh of the same fruit was then pooled into biological replicates (6–7 fruits per replicate, three replicates for 2021 and 2022; 6 fruits per replicate, five replicates for 2023), frozen immediately in liquid nitrogen, and stored at −80 °C until analysis.

Storage Temperature Trial

In the 2022 season, 12 crates with ~100 fruits/crate were harvested at each of H2–H5 and were stored at 0.5 °C, 1.0 °C, 2.0 °C, and 3.0 °C. At each temperature, three crates of fruit were used for firmness (fruit and core) measurement at intervals of 2 to 4 weeks up to 32 weeks, with 20-fruit samples taken across the three crates.

Additional crates of fruit were stored at 1 °C for assessment of shelf-life performance after 2, 4, and 8 weeks of storage. For H2 fruit, two crates of fruit were evaluated after 2, 4, and 8 weeks of storage. However, owing to constraints on fruit volume, for H3 and H4, only one crate of fruit was available for each shelf assessment (after 2, 4, and 8 weeks). From these crates, 20-fruit samples were taken at intervals of 1 to 2 days and measured for fruit firmness, core firmness, and SSC.

Ethylene Ripening Trial

In the 2022 season, the effect of ripening was investigated using fruit from H1–H5. At each harvest, four trays (25 fruits/tray) of fruit were harvested, and two trays were left to ripen at 20 °C, and two trays were ripened with ethylene (20 ppm ethylene for 24 h at 20 °C). Eating-ripe fruits were collected from the ethylene-treated fruit after 3–4 days and from the control, untreated fruit after 25–51 days. The larger range for the untreated fruit reflects the progress of maturation of the fruit between H1 and H5. Twenty individual ripe fruits were sampled from each treatment, and the fruits were randomly allocated to three biological replicates, which were peeled, the pulp combined, and then frozen in liquid nitrogen and stored at −80 °C until analyzed.

1-MCP Response Trial

In the 2021 season, DJK fruit from H1–H4 were used to investigate the effect of 1-MCP (SmartFresh, AgroFresh Inc., Philadelphia, PA, USA) on softening during storage at 1 °C, with the fruit from the 'Maturity and Storage' trial being used as untreated controls. The 1-MCP treatment (+MCP; 0.5 µL/L at 20 °C for 24 h) was applied to three large crates with ~200 fruits/crate, in a 360 L chamber prior to cooling and storage, after which they were stored at 1 °C for up to 20 weeks. During storage, 20-fruit samples from each treatment were removed at intervals of 1–4 weeks up to 20 weeks and measured immediately for fruit firmness and fruit core firmness.

2.3. Fruit Maturity Assessments

Fruit flesh firmness was measured using a Fruit Texture Analyzer (FTA, GÜSS model GS15, GÜSS Manufacturing Ltd., Strand, South Africa) fitted with a 7.9 mm penetrometer probe. The skin and flesh were removed to a depth of ~1 mm, and the probe was driven into the flesh at 5 mm s^{-1} to a displacement of 7.9 mm after triggering at 50 g. The maximum force was recorded as the firmness value in kgf, and this was converted to N, where $1 \text{ kgf} = 9.81 \text{ N}$. Firmness was measured twice at 90° separation at the equator of each fruit, and these values were averaged to give the fruit's flesh firmness value.

The fruit core firmness was also measured with the GÜSS GS15 FTA fitted with a 3 mm diameter probe. The operating parameters were the same as for the flesh firmness measurement. Each fruit was cut transversely 15 mm from the stem end, and the section of fruit with the stem scar was discarded. The measurement was made by inserting the probe into the core, with the core firmness being measured once.

Flesh color was measured as the hue value ($^\circ\text{h}$) with a CR400 Chroma Meter (Konica Minolta, Tokyo, Japan) after removal of skin and flesh to a depth of ~2 mm. Flesh color was measured twice at the equator of the fruit, with two measurements being taken at 90° separation, and their average was recorded as the fruit's flesh color value.

SSC was determined with a digital refractometer (PAL-1, Atago, Tokyo, Japan) for a sample of juice from the stylar end and stem end of the fruit combined in the fruit maturity trial, or from the equator of the fruit in the cold storage trial.

DM was measured by drying a transverse 2 mm slice from the equator of the fruit at 65°C for at least 24 h, and the dried weight was represented as the percentage of the initial fresh weight.

2.4. Storage Disorder Evaluation

Storage disorders of the fruit harvested at different times in 2023 (H1–H7) were quantified after 24 weeks of storage at 1°C (24 wk) and followed by 7 days at 20°C (24 wk + 7 d). The main disorders seen were rot and chilling injury (CI).

The rots were categorized by positions on the fruit: stem-end rot (SER), body rot (BR), and blossom-end rot (BER) [39,40]. The rot incidence at 24 wk + 7 d included the incidence immediately out of storage.

At 24 wk + 7 d, each fruit was cut transversely approximately 1.5–2 cm from the blossom end to assess CI. Where CI was observed, it was classified by severity as slight, moderate, or severe based on the extent and appearance of corky symptoms. Specifically, slight CI was defined as localized, barely visible corky areas; moderate CI as corky patches covering approximately 50% of the surface; and severe CI as extensive, prominent corky areas covering >50% of the surface, or forming a complete ring under the skin (100% of the surface). This classification followed the descriptive categories previously established for *A. chinensis* var. *chinensis* cultivars 'Zesy002' [48] and 'Donghong' [49]. The typical CI symptoms of *A. chinensis* var. *deliciosa* 'Hayward' fruit, water-soaked tissues and granular appearance [50], were rarely observed in the 'Jinyan' fruit, as also reported for 'Donghong' [49].

2.5. Quality Measurement of Ripe Fruit

Tissue samples stored at -80°C were powdered in liquid nitrogen before analyses. Soluble non-reducing sugar was hydrolyzed with concentrated hydrochloric acid (HCl) at 80°C to produce reducing sugar, and then total soluble sugar was determined by spectrophotometry using the 3, 5-dinitrosalicylic acid (DNS) method according to the agricultural industrial standard method of China (NY/T 2742-2015); it is presented as percentage (%) of glucose.

Titrateable acidity (TA) content was determined using 0.1 M sodium hydroxide (NaOH) to titrate the sample solution to pH 8.2 under the usage of an automatic titrator (HI931, Hanna Instruments, RI, USA), basically following the national standard method (GB 12456-2021); its result is reported as percentage (%) of citric acid. The ratios of rSSC and TA (rSSC/TA), sugar and TA (Sugar/TA) were rSSC or sugar content divided by TA content, respectively.

Vitamin C (VitC) content was measured using a 2, 6-dichloroindophenol titrimetric method in the national standard GB 5009.86-2016 using an automatic titrator (HI931, Hanna Instruments, Woonsocket, RI, USA), with data presented as mg/100 g fresh weight (FW).

2.6. Data Analysis

Data are presented as the sample means and standard error of the mean (sem). Significant differences among samples were determined by analysis of variance, with post hoc separation of means by Tukey test at the $p = 0.05$ level. Pearson correlation coefficients were calculated to evaluate the relationships between at-harvest fruit characteristics and postharvest disorder incidence (based on seven harvests in 2023), as well as between at-harvest characteristics and ripe fruit quality attributes (based on 17 harvests across 2021–2023). Plotting, statistical analysis, and correlation analysis were performed using Origin 2024b software (OriginLab Corporation, Northampton, MA, USA) and Genstat 22nd Edition (VSN International Ltd., Hemel Hempstead, UK).

3. Results

3.1. Fruit Growth, Maturation, and Ripening; 2021–2023

‘Jinyan’ fruit showed consistent patterns of change in fresh weight, seed color, fruit flesh firmness, flesh color, SSC, and dry matter for the years 2021–2023, but with small differences in the actual values and inflection points (Figure 2).

The fruit weight increased rapidly up to 60 DAFB, and then at a slower rate until growth ceased at ~140 DAFB (Figure 2A). In 2023, there was some late-season growth, resulting in the fruit being slightly larger in 2023 (~130 g) than in 2021 and 2022 (~115 g). Seed coat color darkened during development from white to light brown and eventually to dark brown/black. The timing of the seed coat color being fully dark was between 105 DAFB in 2023 and 120 DAFB in 2022, with 2021 being intermediate, at 110 DAFB (Figure 2B).

Fruit flesh firmness declined slowly during maturation until there was a change to rapid softening associated with ripening at 159 DAFB in 2021 and 163 DAFB in 2022, but not until later at 196 DAFB in 2023 (Figure 2C). While the timing of the ripening change was similar in 2021 and 2022, the fruits in 2021 were softer overall than in 2022, with the change to ripening occurring at ~69.3 N in 2021 and ~81.7 N in 2022. With the later change to ripening in 2023, the fruits were at ~52.6 N when this occurred.

Flesh color changed during maturation and ripening from ~115 °h to <100 °h at the end of monitoring (Figure 2D). This change is associated with the loss of chlorophyll from the outer pericarp, commonly termed degreening. The rate of color change was similar for each of the years, but the change occurred earlier in 2022 than in the other years.

The change in SSC during development, maturation, and ripening showed a sigmoidal pattern of slow, fast, and slow phases (Figure 2E). Early in development, the SSC was low, at <5%, with no clear change with time. There then followed a period of rapid increase in the SSC. This phase commenced when fruit were still at between 4 and 5% SSC, which was at between 125 and 150 DAFB depending on the year. In 2021, the change occurred at 125 DAFB; in 2022 and 2023, it was at ~150 DAFB. Subsequent monitoring confirmed the later changes in 2023 than in 2021 and 2022. However, the rates of change during this

period were similar apart from the initial rates, which appeared to be higher in 2021 and 2022 than in 2023. The final slow phase of the sigmoidal pattern occurred at ~190 DAFB in 2021 and 2022 and slightly later, at 200 DAFB, in 2023. The SSC at this phase was ~12.4%, 13.3%, and 11.5% in 2021, 2022, and 2023, respectively.

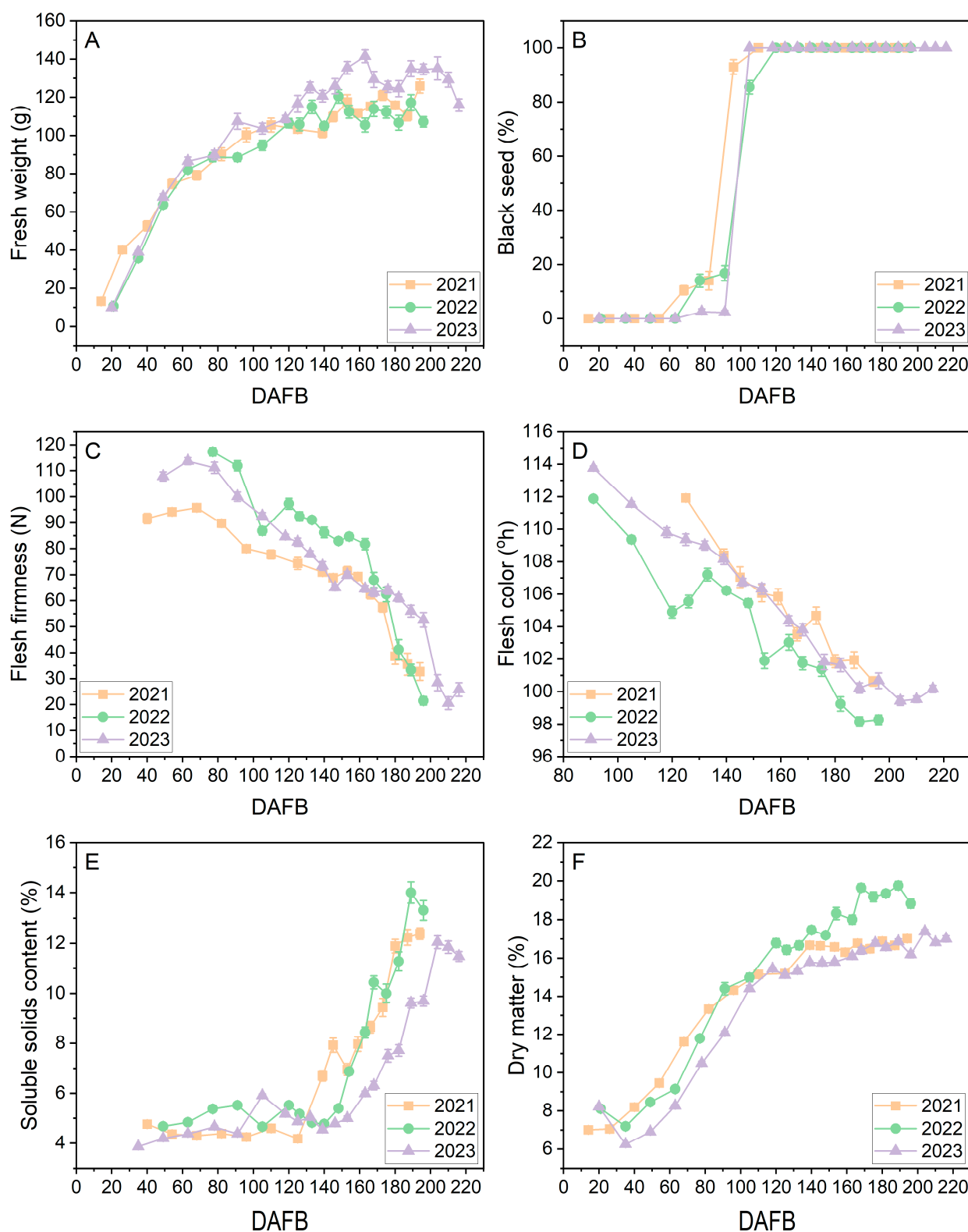


Figure 2. Fresh weight (A), black seed (B), flesh firmness (C), flesh color (D), soluble solids content (E), and dry matter (F) of 'Jinyan' kiwifruit during fruit development in 2021–2023. DAFB = days after full bloom. Values are means $\pm$ sem, $n = 20$.

The dry matter of the fruit increased rapidly from 30–40 DAFB to ~100 DAFB, at which time the accumulation rate slowed (Figure 2F). There was a gradual change into the slower phase, and at the end of monitoring, the dry matter in 2021 and 2023 was ~16.8%, but markedly higher, at ~19.3%, in 2022.

3.2. Softening of Fruit of Different Maturities During Storage; 2021–2023

‘Jinyan’ fruits were harvested at 166 to 194 DAFB (H1–H5) in 2021, 165 to 196 DAFB (H1–H5) in 2022, and 166 to 209 DAFB (H1–H7) in 2023 (Table 1). Fruits were stored at 1 °C and evaluated for flesh and core firmness at up to 32 weeks of storage.

The at-harvest characteristics of the fruit at each harvest are given in Table 1. In all years, the fruit had fully dark seeds and had fully degreened (<100 °h) at H1. In 2021, between H1 and H5, the flesh firmness decreased from 55 N to 32 N, and SSC increased from 8.5% to 12.4%. In 2022, between H1 and H5, the firmness decreased from 77 N to 20 N, and SSC increased from 8.1% to 13.2%. In 2023, between H1 and H7, the firmness decreased from 61 N to 26 N, and SSC increased from 6.6% to 11.2%.

Fruit from all years and harvests had a similar pattern of flesh softening in storage, with a rapid phase followed by a slow phase of softening (Figure 3A,C,E), fitting the expected sigmoidal pattern of kiwifruit softening. However, while Phase 2 and Phase 3 are clear for each softening curve, only in H1 fruit from 2022 and H1 and H2 from 2023 was there a period of slow Phase 1 softening, and even then, only for one week.

Within each year, when the fruits were more mature at harvest, they were softer at harvest and reached Phase 3 sooner in storage. The change from Phase 2 to Phase 3 occurred gradually below 30 N, with Phase 3 being established at ~10 N. The time taken in storage to reach 10 N was longer in less-mature fruit, taking 10–22 weeks in 2021, 12–16 weeks in 2022, and 4–12 weeks in 2023.

When the Phase 2 softening rate was calculated from the actual flesh firmness curves, it was found that the rate decreased with later harvest time, varying from 5.21 to 2.67 N/week in 2021, 8.82 to 1.17 N/week in 2022, and 6.84 to 3.06 N/week in the 2023 season, respectively. This is likely to reflect the starting position within the softening sigmoidal pattern and the fact that the change between phases occurs gradually and not abruptly.

The at-harvest differences in flesh firmness were reduced with time in storage, with the Phase 3 slow softening allowing the firmer, faster-softening fruit to catch up. Hence, by ~12 weeks of storage, there was little difference in firmness among fruit from the different harvests. Once at or below 10 N, the rate of softening differed by harvest maturity, and tended to be less in the more mature fruit, but also seemed to differ year to year.

The fruit core firmness showed a similar pattern of softening as for flesh firmness, fast followed by slow softening, becoming stable at 6–16 weeks of storage depending on harvest time and years (Figure 3B,D,F). As with flesh firmness, the core firmness reached Phase 3 firmness more quickly in later-harvested fruit that were softer at harvest. In addition to the general relationship, the maturity difference was also caused in 2021 and 2023 by the softening curves of the earlier harvests (H1–H3) having flatter (less rapid Phase 2) softening curves than the later harvests (H4 and H5). In addition, the core firmnesses from the different harvests were similar once fruit from all harvests had reached Phase 3.

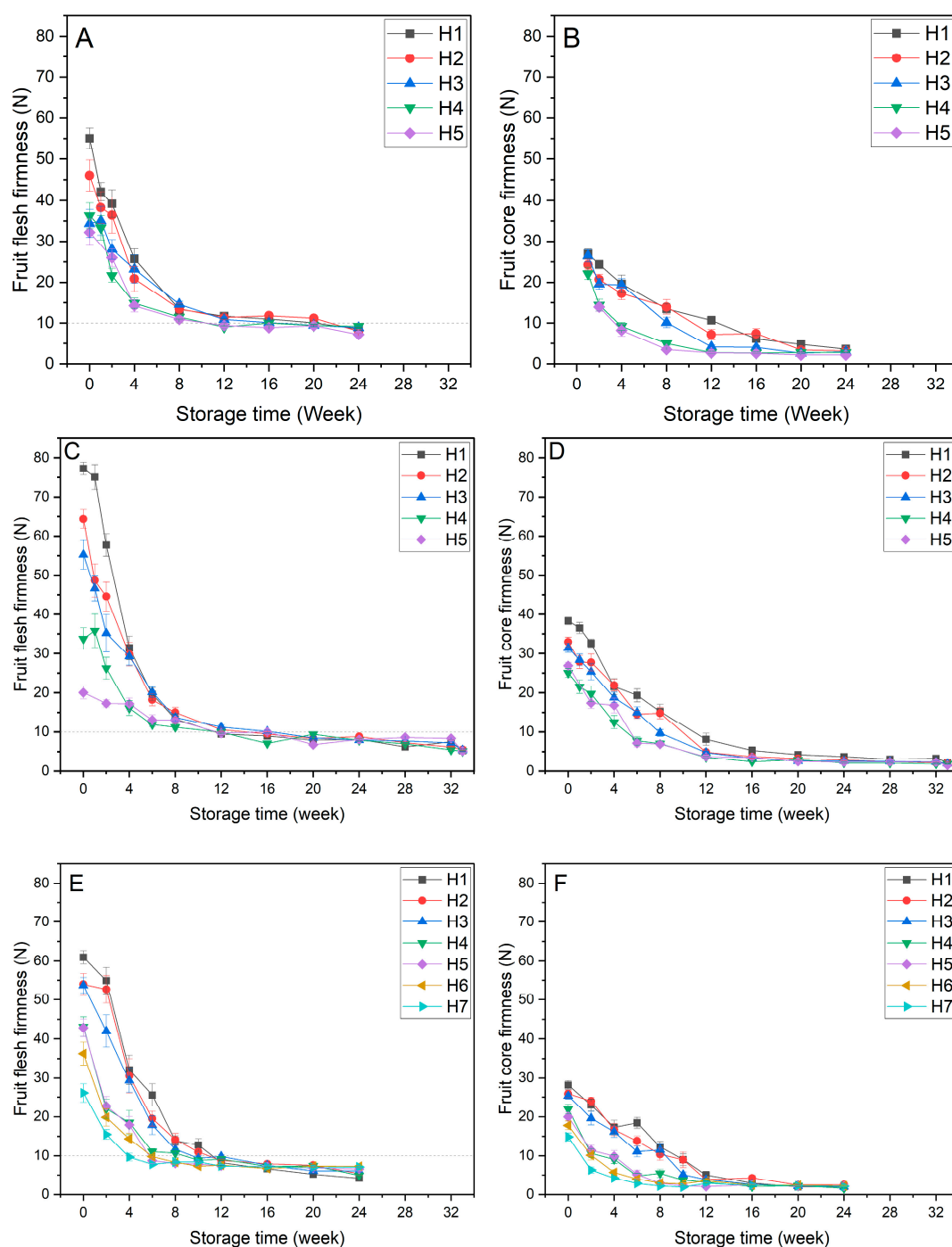


Figure 3. Fruit flesh firmness (A,C,E) and core firmness (B,D,F) of 'Jinyan' kiwifruit harvested at different maturities in 2021 ((A,B), H1–H5), 2022 ((C,D), H1–H5), and 2023 ((E,F), H1–H7) during storage at 1 °C. Values are means $\pm$ sem, $n = 20$.

3.3. Fruit Softening During Storage at Different Temperatures; 2022

The fruits harvested at H2–H5 in 2022 were stored at 0.5 °C, 1.0 °C, 2.0 °C, or 3.0 °C for up to 32 weeks, with flesh and core firmness measured every 2 or 4 weeks. Harvest time and storage temperatures affected flesh and core softening (Figure 4). From the at-harvest flesh firmness, it appears that H2 and H3 fruit were harvested before the start of ripening (firmness >50 N) and H4 and H5 fruit were harvested after ripening had started on the vine (firmness <40 N).

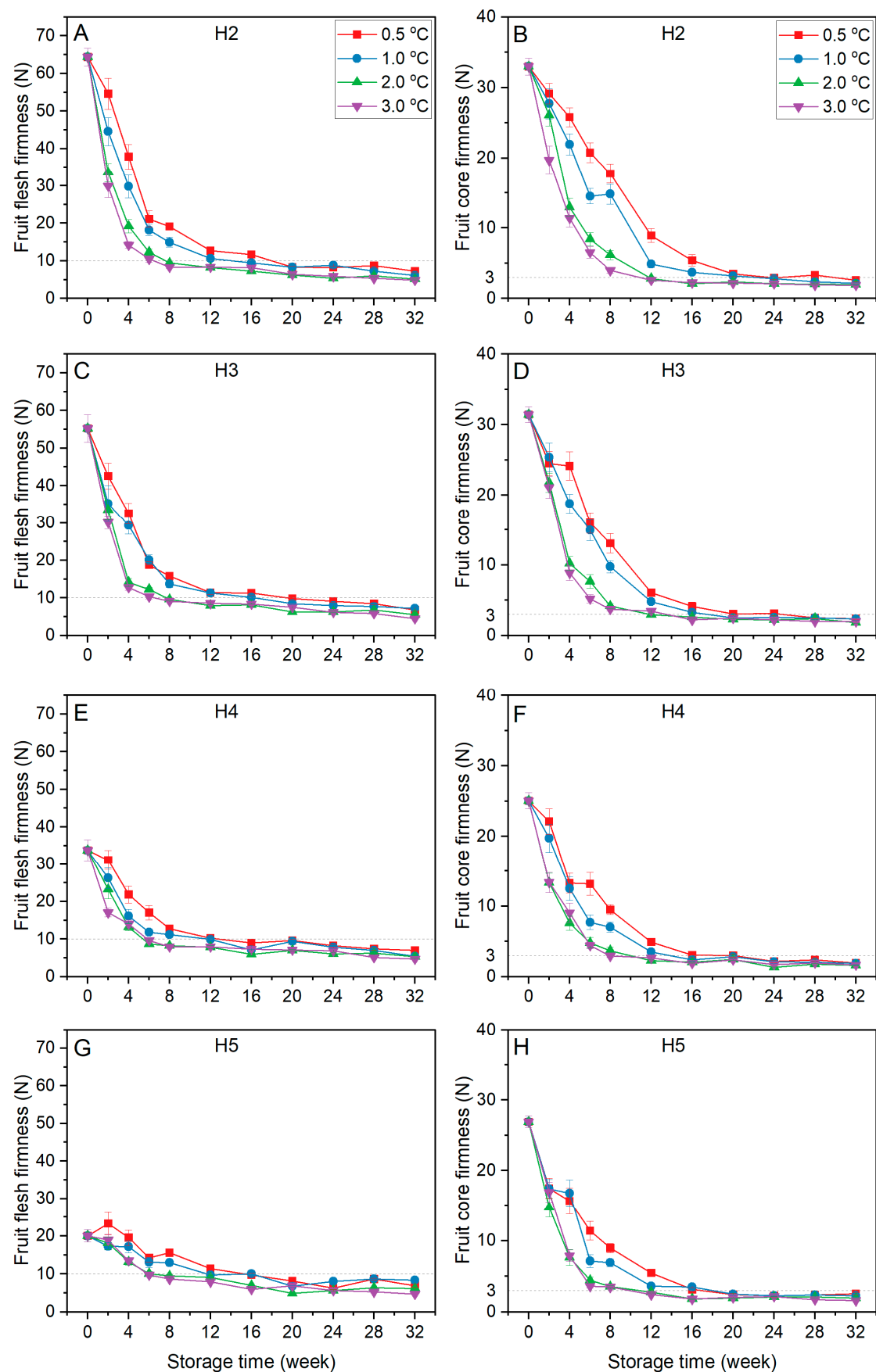


Figure 4. Fruit flesh (A,C,E,G) and core (B,D,F,H) firmness of 'Jinyan' kiwifruit harvested at H2 (174 days after full bloom, DAFB) to H5 (196 DAFB) in 2022 and stored for up to 32 weeks at 0.5 °C, 1.0 °C, 2.0 °C, or 3.0 °C. Values are means $\pm$ sem, $n = 20$.

Firmness of fruit flesh from all harvests (H2–H5) had similar patterns of softening, showing Phase 2 (fast) and Phase 3 (slow) periods of the general three-phase sigmoidal softening pattern (Figure 4). Even for the firmer H2 and H3 fruit, there was no clear Phase 1 slow softening period immediately after harvest.

While the patterns of softening were all exponential decays, there were clear differences caused by temperature. The temperature affected the rates of softening consistently, such that the coldest fruits (0.5 °C and 1.0 °C) were slowest to soften and the warmest (2.0 °C and 3.0 °C) were fastest. Differences in firmness caused by different storage temperatures were significant during the early storage period (0–8 weeks), while differences were largely non-significant during the subsequent storage period. Meanwhile, as harvest time was delayed, the differences in firmness among different temperature treatments became progressively smaller. For H2 to H4 harvests, fruits stored at 0.5 °C and 1.0 °C exhibited the slowest softening, with no statistically significant differences between them, while non-significant differences were observed between the 2.0 °C and 3.0 °C treatments with similarly fast softening. However, the differences between these two pairs could be maintained for up to 6–8 weeks.

What can be seen in the graphs can also be described mathematically, as an example, illustrated by comparing the fruit softening at 0.5 °C and 3.0 °C for fruit from H2 (Figure 4A). A two-term exponential decay was a better fit than a one-term, with R^2 values of 0.979 and 0.998 for softening at 0.5 °C and 3.0 °C, respectively, when fitting the equation:

$$y = a \times \exp(b \times t) + c \times \exp(d \times x)$$

From these equations, the decay rates (b and partially d) were sharper and more pronounced at 3.0 °C than at 0.5 °C.

The faster Phase 2 softening at warmer temperatures resulted in the fruit softening further before the change to Phase 3, and the firmness in Phase 3 remained lower. This difference in firmness was maintained for the rest of the storage period. Phase 3 softening occurred at ~10 N. The change from Phase 2 to Phase 3 was clearest in the H2 and H3 fruit, with the change occurring when ~5 N softer at higher temperatures (~15 N compared with ~20 N). The H4 and H5 fruit showed similar trends in softening linked to temperature, although the change into Phase 3 appeared more gradual.

One method of assessing the effect of temperature on softening is by comparing the time taken to reach a fixed firmness value; in this case, 10 N has been chosen, as below that firmness, the fruits are eating-soft. With fruit softening faster at warmer temperatures, the H2 and H3 fruit reached 10 N firmness between 8 weeks and 18 weeks, and the H4 and H5 fruit reached 10 N between 6 weeks and 12–16 weeks, respectively.

Harvest maturity and storage temperature had similar effects on core softening to those on fruit flesh softening (Figure 4). Similar effects on the pattern of softening included the split between harvests H2 and H3 compared with H4 and H5, and between storage temperatures, warmer (2.0 °C and 3.0 °C) compared with colder temperatures (0.5 °C and 1.0 °C). For core firmness, Phase 3 occurred at a firmness of ~3 N, with the time taken to reach 3 N being between 8 and 12 weeks at warmer temperatures and 20 and 24 weeks at colder temperatures (Figure 4).

3.4. Shelf-Life After Different Durations of Storage; 2022

‘Jinyan’ fruit harvested at H2, H3, and H4 in 2022 were stored at 1 °C for 2, 4, and 8 weeks before transfer to 20 °C for shelf-life evaluation. Fruit flesh firmness, core firmness, and SSC were measured at intervals for up to 25 days.

Harvest maturity and storage duration affected the patterns of flesh and core softening and SSC accumulation (Figure 5). The effect of harvest maturity was reduced with time

in storage as flesh and core softening progressed towards Phase 3 in storage and starch conversion to soluble sugars increased the SSC.

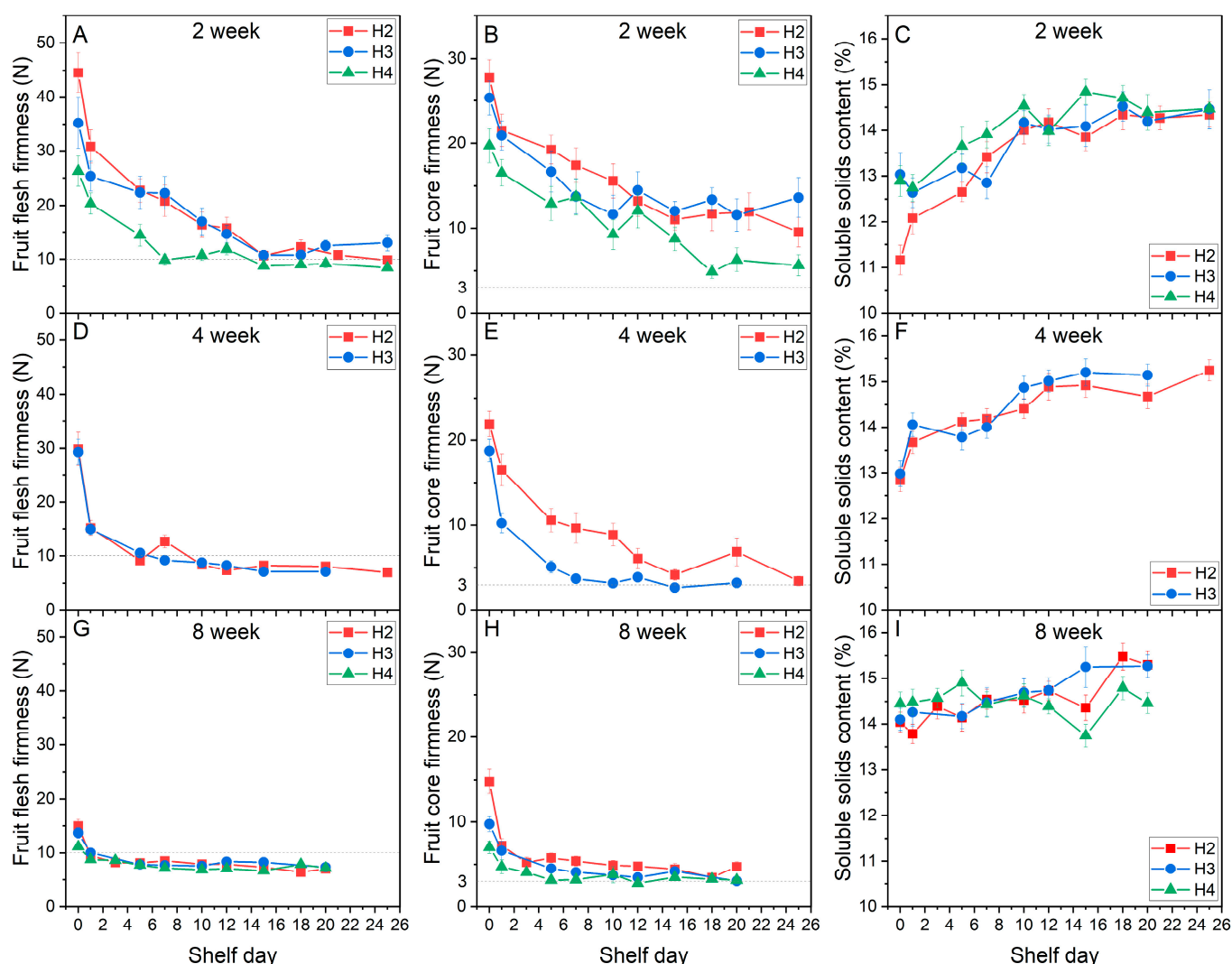


Figure 5. Fruit flesh (A,D,G) and core (B,E,H) firmness and soluble solids content (C,F,I) of ‘Jinyan’ kiwifruit harvested at H2 (174 days after full bloom, DAFB) to H4 (189 DAFB) in 2022, stored for up to 8 weeks at 1 °C. Fruit transferred to 20 °C after 2 weeks (A–C), 4 weeks (D–F), and 8 weeks (G–I) of storage. Values are mean $\pm$ sem, $n = 20$.

An effect of harvest maturity on flesh firmness was obvious in fruit only after 2 weeks of storage, with fruit from H2 and H3 taking ~16 days to reach 10 N, whereas fruit from H4 had softened to 10 N after 7 days (Figure 5). There was no effect of harvest maturity after 4 and 8 weeks of storage, as the fruit had softened markedly in storage. Fruit from all harvests and storage periods maintained their flesh firmness at 20 °C for at least 20 days.

The fruit core softening at 20 °C showed similar effects to flesh firmness, but with the harvest maturity effect lasting slightly longer into storage, with similar firmness values by 8 weeks of storage (Figure 5).

The accumulation of SSC from starch breakdown showed both harvest maturity and storage duration effects (Figure 5). After 2 weeks, the most advanced H4 fruit already had a closer to the maximal SSC than fruit from H3 or H2. After 25 days at 20 °C, the SSC of fruit from all harvests was similar, at ~14.5%. The longer the fruits were in storage, the further the SSC accumulation progressed, until after 8 weeks in storage, the SSC was at, or close to, maximal, at 14–15%. This is consistent with the fruit being fully softened. It is

noticeable that despite using 20-fruit samples, there was considerable sample variability in the SSC data.

3.5. Response of Fruit of Different Maturities to 1-MCP; 2021

Fruit were harvested at H1–H4 in 2021 and fumigated with 1-MCP (+MCP) or not (-MCP) and stored at 1 °C for up to 20 weeks. The fruit flesh and core firmnesses were monitored through storage to determine the response to 1-MCP treatment. Overall, throughout storage, the +MCP fruit had higher flesh firmness than the -MCP fruit, irrespective of harvest maturity: H1 ($p = 0.002$), H2 ($p = 0.028$), H3 ($p = 0.002$), and H4 ($p = 0.083$) (Figure 6). The response to 1-MCP appeared to be dependent on the harvest maturity. For fruit from H1 and H2, the Phase 2 softening appeared to be put on hold before softening resumed at the same rate as in the untreated fruit. Then, when the fruit reached Phase 3, the treated fruit held at a firmness of 2–3 N firmer than the untreated fruit. For H3 and H4 fruit, with much of the Phase 2 softening having been completed, the treatment resulted in slightly firmer fruit throughout Phase 3.

The softening of the fruit core in response to 1-MCP was similar to that of the fruit flesh, with statistically significant effects of 1-MCP improving firmness retention at $p < 0.001$ for all harvests (Figure 6). The treatment delayed the core softening in Phase 2, and the core remained slightly firmer during Phase 3.

3.6. Storage Disorders in Fruit of Different Maturities; 2023

Storage disorders were quantified for ‘Jinyan’ fruit harvested at H1–H7 in 2023 that were stored for 24 weeks at 1 °C followed by 7 days at 20 °C (24 wk + 7 d) before assessment. The main disorders observed were rot and CI. The early-harvested fruit (H1 and H2) had the highest incidence of total CI (52.0% and 47.8%, respectively; Table 2). The more mature H3–H5 fruit had a low incidence of total CI (<5.2%), and there was no CI seen in the late-harvested (H6 and H7) fruit (Table 2). This decrease in the incidence of CI with increased harvest maturity was observed in all severity categories.

The incidence of total rot after 24 weeks of storage was between 15.4% and 43.6%, tending to be higher in the earlier harvested fruit (Table 2). The rot incidences increased to between 25.9% and 89.0% after 7 days at 20 °C, with a clear trend for a decrease in the more mature fruit. For fruit assessed at both 24 wk and 24 wk + 7 d, there was a statistical separation of the first four harvests from the last three harvests, being clearest after the 7-day shelf-life assessment.

The differences in the total rot incidence between fruit from different harvests were largely driven by body rots, for which at 24 wk + 7 d were in the general range 20–80%, with markedly lower incidences of stem end ($\leq 7.5\%$) and blossom end ($\leq 9.0\%$) rots (Table 2). For both stem-end and blossom-end rots, there was no clear trend with harvest maturity.

With the changing incidences of CI and rots with maturity, there were some strong correlations between at-harvest fruit characteristics and disorder incidence (Table 3). For total CI, the correlation coefficients were 0.72 with flesh color, 0.76 with firmness, -0.86 with SSC, and -0.89 with DM. With the exception of DM, these are understandable, as there were clear trends with maturity in the at-harvest characteristics (Table 1). The changes in DM were both small and less clear. No correlation coefficients for at-harvest characteristics were >0.5 with stem-end or blossom-end rots (Table 3). For body rots, there were strong correlations with firmness ($r = 0.83$), flesh color ($r = 0.78$), and SSC ($r = -0.90$). For both body rots and total rots, there were correlations with total CI ($r = 0.70$ and 0.68 , respectively).

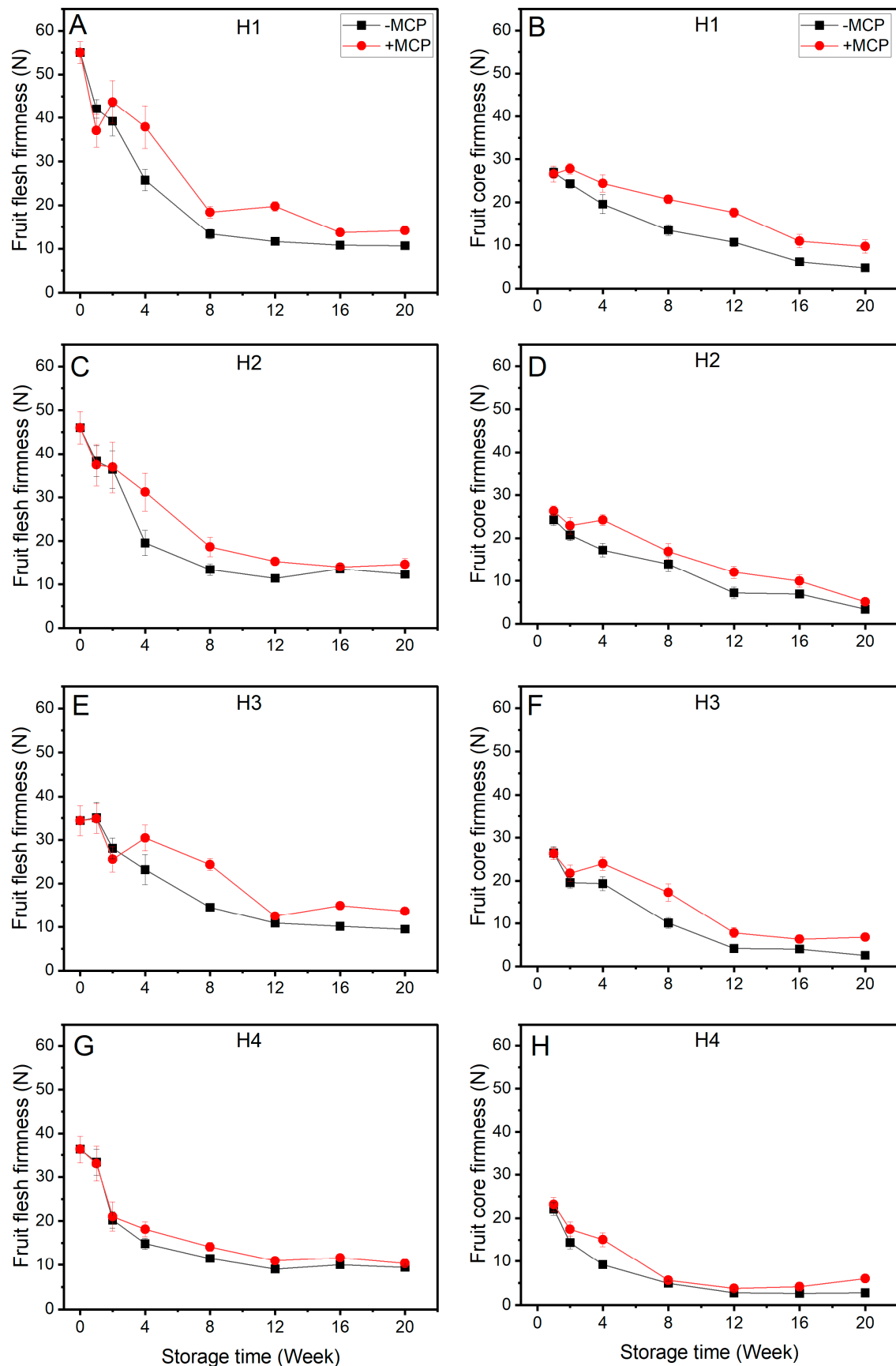


Figure 6. Fruit flesh (A,C,E,G) and core (B,D,F,H) firmness of 'Jinyan' kiwifruit harvested at H1–H4 in 2021, treated with 1-MCP (+MCP, ●) or not (–MCP, ■) and stored at 1 °C for up to 20 weeks. 1-MCP was applied at 0.5 $\mu\text{L/L}$ at 20 °C for 24 h. Values are means $\pm$ sem, $n = 20$.

Table 2. Incidence of chilling injury and rot in ‘Jinyan’ kiwifruit harvested seven times (H1–H7) in 2023 and stored for 24 weeks at 1 °C (24 wk) followed by 7 days at 20 °C (24 wk + 7 d). Values are means ± sem, *n* = 3 crates with ~100 fruits/crate. Within each storage assessment, values in a column not sharing a common letter differ at *p* = 0.05.

Sample	Harvest	Chilling Injury Incidence (%)				Rot Incidence (%) *			
		Slight	Moderate	Severe	Total	Stem	Body	Blossom	Total
24 wk	H1					3.0 ± 0.98 ^a	26.6 ± 3.41 ^{ab}	3.7 ± 1.33 ^a	33.2 ± 3.65 ^{ab}
	H2					4.1 ± 0.76 ^a	31.2 ± 5.90 ^a	8.2 ± 3.81 ^a	43.6 ± 3.84 ^a
	H3					2.5 ± 1.63 ^a	23.1 ± 5.12 ^{ab}	1.8 ± 0.97 ^a	27.4 ± 7.21 ^{bc}
	H4					1.8 ± 0.36 ^a	26.8 ± 0.73 ^{ab}	2.6 ± 0.38 ^a	31.3 ± 0.75 ^{ab}
	H5					0.4 ± 0.37 ^a	12.8 ± 1.47 ^b	2.2 ± 0.67 ^a	15.4 ± 2.12 ^c
	H6					2.0 ± 1.15 ^a	16.6 ± 0.87 ^{ab}	3.6 ± 0.32 ^a	22.2 ± 1.41 ^{bc}
	H7					4.3 ± 1.40 ^a	18.4 ± 0.92 ^{ab}	3.9 ± 0.64 ^a	26.6 ± 0.86 ^{bc}
24 wk + 7 d	H1	11.4 ± 2.55 ^a	11.4 ± 2.08 ^a	29.1 ± 2.78 ^a	52.0 ± 4.30 ^a	3.0 ± 0.98 ^{ab}	81.2 ± 2.14 ^a	4.8 ± 0.38 ^a	89.0 ± 2.52 ^a
	H2	8.5 ± 2.52 ^a	12.3 ± 2.74 ^a	21.0 ± 2.81 ^b	41.8 ± 2.23 ^b	4.5 ± 0.67 ^{ab}	64.1 ± 7.38 ^b	9.0 ± 3.96 ^a	77.6 ± 2.85 ^a
	H3	1.4 ± 0.29 ^b	0.7 ± 0.35 ^b	3.1 ± 1.12 ^c	5.2 ± 1.67 ^c	4.3 ± 1.75 ^{ab}	64.5 ± 2.5 ^{ab}	7.8 ± 1.11 ^a	76.6 ± 1.92 ^a
	H4	0.7 ± 0.37 ^b	0	0.7 ± 0.36 ^c	1.5 ± 0.37 ^c	3.0 ± 0.77 ^{ab}	65.5 ± 1.72 ^{ab}	5.9 ± 0.29 ^a	74.3 ± 1.34 ^a
	H5	0.7 ± 0.70 ^b	0.7 ± 0.70 ^b	0.7 ± 0.74 ^c	2.1 ± 1.22 ^c	0.7 ± 0.36 ^b	22.6 ± 2.33 ^c	2.6 ± 0.40 ^a	25.9 ± 2.30 ^c
	H6	0	0	0	0	4.7 ± 1.22 ^{ab}	24.5 ± 0.29 ^c	8.6 ± 1.37 ^a	37.8 ± 2.50 ^{bc}
	H7	0	0	0	0	7.5 ± 1.91 ^a	26.8 ± 0.37 ^c	7.8 ± 1.60 ^a	42.2 ± 2.30 ^b

* Rot incidence at 24 wk + 7 d includes those rots present at 24 wk.

Table 3. Correlations between at-harvest ‘Jinyan’ kiwifruit characteristics (flesh firmness, flesh color, soluble solids content (SSC), dry matter) and the incidences of chilling injury (CI; slight, moderate and severe severity and total) and rots (stem-end = SER; body = BR; blossom-end = BER and total rots) after 24 weeks of storage at 1 °C followed by 7 days at 20 °C. Values based on the mean data from seven harvests.

	Flesh	Flesh	SSC	Dry	Chilling Injury				Rots			
	Firmness	Color		Matter	Slight	Moderate	Severe	Total	SER	BR	BER	Total
Flesh firmness	1.00											
Flesh color	0.70	1.00										
SSC	−0.96	−0.82	1.00									
Dry matter	−0.83	−0.79	0.86	1.00								
CI Slight	0.78	0.75	−0.87	−0.90	1.00							
CI Moderate	0.72	0.58	−0.79	−0.83	0.97	1.00						
CI Severe	0.77	0.76	−0.87	−0.90	1.00	0.97	1.00					
CI Total	0.76	0.72	−0.86	−0.89	1.00	0.98	1.00	1.00				
Rot SER	−0.49	−0.24	0.30	0.41	−0.16	−0.09	−0.13	−0.13	1.00			
Rot BR	0.83	0.78	−0.90	−0.60	0.72	0.63	0.71	0.70	−0.15	1.00		
Rot BER	−0.17	−0.32	0.05	0.34	−0.04	0.07	−0.03	−0.01	0.79	0.04	1.00	
Rot Total	0.77	0.72	−0.86	−0.53	0.70	0.63	0.69	0.68	0.01	0.99	0.21	1.00

3.7. Internal Quality of Ripe Fruit; 2021–2023

The internal quality (rSSC, soluble sugars, TA, VitC) of ripe (<10 N) ‘Jinyan’ fruits harvested at different maturities was determined after storage and ripening in 2021–2023. In 2021, ripe fruits were obtained from five harvests after storage at 1 °C for 16 weeks. In 2022, ripe fruits were obtained from five harvests after storage at 1 °C for 20 weeks, or allowed to ripen immediately after harvest, either with or without ethylene treatment. In 2023, ripe fruits were obtained from seven harvests after storage at 1 °C for 24 weeks.

All samples of fruit had a firmness <10 N, with an average of 5–8 N, although in 2022, the ethylene-ripened fruits (ETH) were slightly softer, at ~4–5 N, than fruits ripened without ethylene (RT) or during storage at 1 °C (CT). In all 3 years, for fruit ripened during storage, early-harvested fruit tended to have a lower rSSC than late-harvested fruit (Table 4). However, the separation among harvests was gradual. In 2021, H1 and H2 fruit had lower rSSC than H3, H4, and H5 fruit. In 2023, H1 fruit had the lowest rSSC, statistically lower than H2 and H4–H7 fruit. In 2022, there was no statistical separation for rSSC among harvests when ripened the same way. However, in 2022, whilst there was no consistent trend for a difference in rSSC with harvest maturity, within each harvest, the CT fruit had the lowest rSSC, and this was consistently lower than that of the ETH fruit. At no harvest was there a difference between ETH and RT fruit. The overall average rSSC in 2022 fruit tended to be higher than in 2021 or 2023. Soluble sugar content revealed similar trends to those of rSSC, with few statistical differences (Table 4).

For all years, harvests, and ripening conditions, TA was consistent, with mean values of 1.0–1.1% TA and few statistically significant differences (Table 4). However, in 2021 and 2023, earlier harvests tended to be closer to 1.0% TA and later harvests to 1.1% TA. With very similar TA values for all samples, the ratios of rSSC/TA and sugar/TA were largely a reflection of the differences in rSSC and soluble sugars, respectively (Table 4). Additionally, with the TA values being at or close to 1.0, the ratios were numerically very similar to the rSSC and soluble sugar values and tended to retain statistical differences.

There was no overall significant trend of VitC with maturity, possibly because of replicate variability, as there was a trend for higher average values in the later-harvested fruit in both 2021 and 2023 (Table 4). However, there did appear to be a seasonal effect, with the VitC in 2021 being higher (range ~90–100) than in 2023 (range 80–90).

Correlations between rSSC, soluble sugars, TA, and VitC and at-harvest characteristics based on the mean data of the fruit harvested at different times in the three years, demonstrated that dry matter at harvest was positively correlated with rSSC ($r = 0.82$) and VitC ($r = 0.72$), but not with soluble sugar content ($r = 0.22$; Table 5).

Table 4. The ripe fruit soluble solids content (rSSC), soluble sugar, titratable acidity (TA), and vitamin C (VitC) content of ‘Jinyan’ kiwifruit harvested at different maturities during 2021–2023. Fruit were ripened to <10 N during storage at 1 °C (CT) or immediately after harvest at 20 °C with (ETH; 20 ppm for 24 h) or without (RT) ethylene. The CT fruits were collected after 16, 20, and 24 weeks of storage in 2021, 2022, and 2023, respectively. In 2022, the RT fruits were collected after 25–51 days, and the ETH fruits after 3–4 days. Values are means $\pm$ sem, $n = 3$ (for 2021 and 2022) or $n = 5$ (for 2023), except for fruit firmness and rSSC ($n = 20$ for 2021 and 2022, or $n = 30$ for 2023). Within each year, values not sharing a common letter differ at $p = 0.05$.

Year	Harvest	DAFB *	Ripened	Flesh Firmness When Ripe (N)	rSSC (%)	Sugar (%)	TA (%)	VitC (mg/100 g)	rSSC/TA	Sugar/TA
2021	H1	166	CT	7.8 $\pm$ 0.5 ^a	12.0 $\pm$ 0.3 ^b	8.7 $\pm$ 0.0 ^a	1.03 $\pm$ 0.01 ^b	92.6 $\pm$ 2.8 ^{ab}	11.7 $\pm$ 0.3 ^{ab}	8.5 $\pm$ 0.0 ^a
	H2	173	CT	8.6 $\pm$ 0.4 ^a	11.6 $\pm$ 0.3 ^b	7.8 $\pm$ 0.1 ^b	1.11 $\pm$ 0.02 ^a	90.7 $\pm$ 2.5 ^b	10.4 $\pm$ 0.4 ^b	7.0 $\pm$ 0.2 ^b
	H3	180	CT	8.1 $\pm$ 0.3 ^a	13.3 $\pm$ 0.2 ^a	9.0 $\pm$ 0.2 ^a	1.03 $\pm$ 0.01 ^b	98.0 $\pm$ 1.7 ^{ab}	12.9 $\pm$ 0.3 ^a	8.8 $\pm$ 0.3 ^a
	H4	187	CT	7.9 $\pm$ 0.3 ^a	13.1 $\pm$ 0.2 ^a	8.8 $\pm$ 0.3 ^a	1.13 $\pm$ 0.02 ^a	98.1 $\pm$ 1.7 ^{ab}	11.6 $\pm$ 0.3 ^{ab}	7.8 $\pm$ 0.3 ^{ab}
	H5	194	CT	8.3 $\pm$ 0.3 ^a	13.5 $\pm$ 0.2 ^a	8.8 $\pm$ 0.2 ^a	1.11 $\pm$ 0.01 ^a	101.1 $\pm$ 1.1 ^a	12.1 $\pm$ 0.2 ^a	7.9 $\pm$ 0.2 ^{ab}
2022	H1	165	ETH	4.7 $\pm$ 0.3 ^{ef}	15.0 $\pm$ 0.2 ^{ab}	10.1 $\pm$ 0.3 ^{ab}	1.06 $\pm$ 0.02 ^a	ND *	14.1 $\pm$ 0.5 ^{abc}	9.6 $\pm$ 0.5 ^{ab}
	H1	165	RT	9.0 $\pm$ 0.6 ^a	14.4 $\pm$ 0.2 ^{abcd}	9.6 $\pm$ 0.1 ^{ab}	1.05 $\pm$ 0.01 ^a	ND *	13.7 $\pm$ 0.3 ^{abc}	9.2 $\pm$ 0.1 ^{ab}
	H1	165	CT	6.9 $\pm$ 0.3 ^{bcd}	13.8 $\pm$ 0.3 ^{cd}	9.1 $\pm$ 0.2 ^b	1.05 $\pm$ 0.04 ^a	ND *	13.2 $\pm$ 0.3 ^{bc}	8.6 $\pm$ 0.2 ^b
	H2	174	ETH	4.5 $\pm$ 0.3 ^f	15.3 $\pm$ 0.2 ^a	10.1 $\pm$ 0.3 ^{ab}	1.01 $\pm$ 0.02 ^a	ND *	15.1 $\pm$ 0.2 ^{ab}	10.0 $\pm$ 0.2 ^{ab}
	H2	174	RT	8.0 $\pm$ 0.4 ^{ab}	14.7 $\pm$ 0.2 ^{abcd}	10.1 $\pm$ 0.4 ^{ab}	1.06 $\pm$ 0.02 ^a	ND *	13.8 $\pm$ 0.4 ^{abc}	9.5 $\pm$ 0.2 ^{ab}
	H2	174	CT	7.5 $\pm$ 0.3 ^{abc}	13.6 $\pm$ 0.3 ^d	9.3 $\pm$ 0.4 ^b	1.13 $\pm$ 0.04 ^a	ND *	12.0 $\pm$ 0.6 ^c	8.2 $\pm$ 0.1 ^b
	H3	182	ETH	5.5 $\pm$ 0.3 ^{def}	14.8 $\pm$ 0.2 ^{abc}	9.7 $\pm$ 0.2 ^{ab}	1.06 $\pm$ 0.04 ^a	ND *	14.06 $\pm$ 0.3 ^{abc}	9.1 $\pm$ 0.6 ^{ab}
	H3	182	RT	6.3 $\pm$ 0.3 ^{cd}	14.8 $\pm$ 0.2 ^{abc}	9.9 $\pm$ 0.1 ^{ab}	1.04 $\pm$ 0.02 ^a	ND *	14.2 $\pm$ 0.6 ^{abc}	9.5 $\pm$ 0.2 ^{ab}
	H3	182	CT	7.2 $\pm$ 0.3 ^{bc}	14.4 $\pm$ 0.2 ^{abcd}	9.8 $\pm$ 0.2 ^{ab}	1.06 $\pm$ 0.02 ^a	ND *	13.6 $\pm$ 0.4 ^{abc}	9.2 $\pm$ 0.1 ^{ab}
	H4	189	ETH	4.0 $\pm$ 0.3 ^f	15.4 $\pm$ 0.3 ^a	10.1 $\pm$ 0.2 ^{ab}	0.98 $\pm$ 0.04 ^a	ND *	15.8 $\pm$ 0.6 ^a	10.4 $\pm$ 0.6 ^a
	H4	189	RT	6.8 $\pm$ 0.4 ^{bcd}	14.7 $\pm$ 0.2 ^{abcd}	9.9 $\pm$ 0.3 ^{ab}	1.00 $\pm$ 0.02 ^a	ND *	14.7 $\pm$ 0.5 ^{ab}	9.9 $\pm$ 0.2 ^{ab}
	H4	189	CT	6.2 $\pm$ 0.3 ^{cde}	13.9 $\pm$ 0.3 ^{bcd}	9.8 $\pm$ 0.5 ^{ab}	1.08 $\pm$ 0.01 ^a	ND *	12.9 $\pm$ 0.5 ^{bc}	9.1 $\pm$ 0.4 ^{ab}
	H5	196	ETH	4.6 $\pm$ 0.2 ^{ef}	15.4 $\pm$ 0.2 ^a	10.7 $\pm$ 0.2 ^a	1.03 $\pm$ 0.04 ^a	ND *	15.0 $\pm$ 0.6 ^{ab}	10.5 $\pm$ 0.6 ^a
	H5	196	RT	8.1 $\pm$ 0.4 ^{ab}	15.4 $\pm$ 0.3 ^a	10.8 $\pm$ 0.1 ^a	1.01 $\pm$ 0.03 ^a	ND *	15.3 $\pm$ 0.5 ^{ab}	10.8 $\pm$ 0.3 ^a
	H5	196	CT	8.0 $\pm$ 0.3 ^{ab}	14.1 $\pm$ 0.3 ^{bcd}	10.2 $\pm$ 0.0 ^{ab}	1.05 $\pm$ 0.04 ^a	ND *	13.5 $\pm$ 0.7 ^{abc}	9.7 $\pm$ 0.3 ^{ab}
2023	H1	166	CT	3.5 $\pm$ 0.2 ^c	12.1 $\pm$ 0.2 ^c	9.0 $\pm$ 0.4 ^c	0.95 $\pm$ 0.02 ^d	79.7 $\pm$ 4.8 ^b	12.7 $\pm$ 0.1 ^{ab}	9.5 $\pm$ 0.3 ^b
	H2	173	CT	4.4 $\pm$ 0.2 ^{bc}	13.3 $\pm$ 0.2 ^{ab}	9.8 $\pm$ 0.2 ^{bc}	0.99 $\pm$ 0.02 ^{cd}	85.7 $\pm$ 2.5 ^{ab}	13.4 $\pm$ 0.1 ^a	9.9 $\pm$ 0.2 ^{ab}
	H3	181	CT	5.8 $\pm$ 0.2 ^a	12.6 $\pm$ 0.2 ^{bc}	10.1 $\pm$ 0.1 ^{ab}	1.02 $\pm$ 0.02 ^{abc}	89.3 $\pm$ 1.5 ^{ab}	12.3 $\pm$ 0.2 ^{ab}	9.8 $\pm$ 0.2 ^{ab}
	H4	188	CT	5.0 $\pm$ 0.2 ^{ab}	13.1 $\pm$ 0.2 ^{ab}	10.7 $\pm$ 0.2 ^{ab}	1.01 $\pm$ 0.01 ^{bcd}	96.0 $\pm$ 1.5 ^a	13.0 $\pm$ 0.2 ^{ab}	10.6 $\pm$ 0.2 ^a
	H5	195	CT	5.7 $\pm$ 0.2 ^a	13.3 $\pm$ 0.2 ^{ab}	10.9 $\pm$ 0.2 ^a	1.09 $\pm$ 0.01 ^a	94.9 $\pm$ 2.8 ^a	12.2 $\pm$ 0.3 ^b	10.0 $\pm$ 0.2 ^{ab}
	H6	202	CT	5.9 $\pm$ 0.3 ^a	13.2 $\pm$ 0.2 ^{ab}	10.5 $\pm$ 0.2 ^{ab}	1.07 $\pm$ 0.02 ^{ab}	93.1 $\pm$ 2.1 ^a	12.3 $\pm$ 0.4 ^{ab}	9.9 $\pm$ 0.4 ^{ab}
	H7	209	CT	5.4 $\pm$ 0.2 ^a	13.9 $\pm$ 0.2 ^a	11.0 $\pm$ 0.1 ^a	1.09 $\pm$ 0.01 ^a	91.2 $\pm$ 3.0 ^{ab}	12.7 $\pm$ 0.2 ^{ab}	10.0 $\pm$ 0.2 ^{ab}

* ND—not determined because of equipment failure. DAFB = days after full bloom.

Table 5. Correlations between at-harvest fruit characteristics (weight, firmness, flesh color, soluble solids content (SSC), dry matter (DM)) and quality traits of ripe ‘Jinyan’ kiwifruit (firmness, rSSC, sugar, titratable acidity (TA), vitamin C (VitC), ratios of rSSC/TA and Sugar/TA). Values are the mean data from a total of 17 harvests across 2021–2023.

Category	Traits	Weight	Firmness	Flesh Color	SSC	DM	Firmness	rSSC	Sugar	TA	VitC	rSSC/TA	Sugar/TA
At-harvest	Weight	1.00											
	Firmness	−0.06	1.00										
	Flesh color	0.13	0.57	1.00									
	SSC	−0.36	−0.79	−0.56	1.00								
	DM	−0.67	−0.10	−0.46	0.57	1.00							
Ripe	Firmness	−0.49	−0.20	−0.07	0.53	0.31	1.00						
	rSSC	−0.41	−0.23	−0.48	0.55	0.82	0.06	1.00					
	Sugar	0.39	−0.31	−0.56	0.18	0.22	−0.56	0.50	1.00				
	TA	−0.27	−0.29	−0.16	0.68	0.38	0.63	0.26	−0.14	1.00			
	VitC	−0.16	−0.72	−0.20	0.85	0.72	0.70	0.45	−0.03	0.68	1.00		
	rSSC/TA	−0.19	0.00	−0.31	0.01	0.46	−0.39	0.71	0.53	−0.50	−0.18	1.00	
	Sugar/TA	0.46	−0.15	−0.40	−0.14	0.01	−0.75	0.29	0.90	−0.56	−0.31	0.65	1.00

4. Discussion

The findings from the seven areas of research undertaken have illustrated comprehensively the linkages between the fruit maturity and storage and ripening conditions on the postharvest performance (softening and disorders) and eating quality of ‘Jinyan’ kiwifruit.

For the three seasons examined for fruit maturation, the patterns of changes in fruit composition were similar, although some differences in the timing of critical events could be seen. When considering kiwifruit maturation, three elements appear as significant markers: the change to dark seeds, the cessation of growth, and the final change to ripening based on the rate of softening [51]. Despite some seasonal differences in temperatures and rainfall, the timing of seed color change was within a 10-day window for all three seasons, being complete by ~110–120 DAFB. For all seasons, the majority of the change occurred within one week, suggesting that the change in 2021 occurred about 5 days earlier than in 2022 and 2023.

Identifying the cessation of growth from the at-harvest fresh weights was made difficult by the “noise” in the data. While it appeared that in all seasons, growth ceased at ~140–160 DAFB, more precise data would require the use of repeated caliper measurements on tagged fruit [52]. It should be noted that although some late-harvest fruits showed slightly lower average weights than early-harvest fruits, these differences were mostly non-significant and likely reflect sampling bias (early-season preference for larger fruits), as fruit weight had already reached a plateau by physiological maturity.

Finally, the change in ripening assessed by the increased rate of softening occurred at ~170–200 DAFB, with fruit in 2023 ripening later than in 2021 and 2022. In addition, the flesh degreening caused by chlorophyll degradation occurred earliest in 2022, by a few days. Despite early suggestions that the flesh color change in yellow-fleshed kiwifruit is associated with ripening [53], later observations have shown that it is not associated with maturation or ripening [51].

The weather in 2022 was hot and dry, with the period from ~90 to 120 DAFB most affected, although the period from flowering tended to be warmer and drier in 2022 than in 2021 and 2023. This difference in environment seems to have made relatively little difference to the composition of the fruit, with the exception of the fruit degreening. With daytime temperatures approaching 40 °C, it would be expected that there might be an effect on the fruit [54]. Alternatively, it may be that the 2022 environment was not sufficiently different from that of 2021 and 2023, although the markedly lower daily maximum temperatures in August 2021 would suggest otherwise.

The flesh softening pattern in storage was as would be expected [16], a short or no Phase 1 slow-softening period followed by rapid Phase 2 softening, until a slow Phase 3 softening at or below 10 N. Taking the 10 N firmness as a point for comparison, the earlier-harvested fruit (>50 N at harvest) tended to reach this firmness later than the later-harvested fruit (<40 N). The prolonged slow softening at Phase 3 is of commercial benefit, whereby the fruits do not soften excessively. This also depends on how the fruits soften during holding at higher ‘shelf’ temperatures; commonly, holding fruit at 20 °C is used to test this. The limited shelf investigation suggested that even at 20 °C, after up to 8 weeks of storage, the fruit maintained the ~6–8 N flesh firmness for a prolonged period of 2–3 weeks. The softening of the core in storage is as would have been expected, keeping in step with flesh softening, such that it is rare for ‘Jinyan’ fruit to have what is termed a ‘hard core’ when the fruit is eating-ripe [38].

As with other reports for kiwifruit [24,25], the application of the ethylene action inhibitor 1-MCP did slow softening of ‘Jinyan’ fruit, although the numerical difference was small. This is commonly seen, whereby despite kiwifruit generally softening in the absence of increased ethylene production, the ethylene action inhibitor 1-MCP is capable of

making a small impression on the softening rate. However, for kiwifruit, when close to the minimum firmness limit on arrival in markets, a small, 2–3 N improvement in the flesh firmness can make the difference between fruit lots being acceptable or being rejected for having too many fruits being too soft [55].

Thus far, the impact of maturity on postharvest performance has been discussed in terms of fruit softening. However, a major component of quality is the freedom from defects, of which CI is a major defect strongly linked with at-harvest maturity [1]. For ‘Jinyan’ fruit in 2023, a major change in the susceptibility of fruit to CI occurred between H2 and H3, where the total incidence reduced from ~40% to ~5%, and with total elimination of CI in fruit from H6 and H7. The change between H2 and H3 occurred between 170 and 180 DAFB, when fruit were at ~8–8.5% SSC and ~53–54 N firmness. These values appear similar and do not suggest a major difference in the fruit SSC and firmness; however, H1 and H2 fruit in 2023 had a short Phase 1 softening period in storage (Figure 3E), suggesting a lack of maturity when harvested. This lack of softening immediately in storage has been associated with chilling sensitivity in other kiwifruit cultivars [56].

It should also be considered that CI incidence tends to be proportional depending on the maturity of the fruit. Only at the extremes of maturity is it possible to achieve 100% damaged or sound fruit, but there is a wide range of maturity between the extremes, for which only a proportion of the fruit will be affected. The period over which the fruits lose sensitivity was shown in *A. chinensis* var. *chinensis* ‘Hort16A’ and *A. chinensis* var. *deliciosa* ‘Hayward’ to occur over about 4–6 weeks of development on the vine [17,57]. Additionally, CI may develop later in storage, and, thus, the incidence at a single assessment time may not tell the full story unless late in storage, as was done here after 24 weeks of storage.

There were significant numbers of rots in the fruit after storage. In the early-harvested fruit, many of the body rots were associated with fruit that had chilling damage, as has been noted previously for ‘Hort16A’ kiwifruit [40]. However, whilst the rot incidence was reduced in more mature fruit, coincident with the reduction in chilling incidence, there was still a significant incidence of rot in the later-harvested fruit. These rots in otherwise sound fruit may be associated with late-harvested fruit being ripe relatively early in storage. The longer fruits are held whilst soft, the greater the opportunity for rot to develop. These rots in ripe fruit are called ripe rots as they normally develop only once the fruits are ripe [39]. Identification of the fungal species growing on the fruit would probably discriminate between opportunistic species growing on the chilling-damaged fruit and those growing specifically on sound but ripe fruit.

If the fruit has retained sufficient firmness and is free from disorder, it must still taste good when ready to eat, normally judged by being at the correct flesh firmness [31]. Consumer liking of kiwifruit is strongly driven by the rSSC of the fruit when at the correct firmness. This can, to some degree, be predicted from the dry matter of the fruit measured at harvest [3]. The higher rSSC in the fruit from 2022 may, therefore, be associated with the higher at-harvest dry matter identified for that year. The effects of the ripening methods in 2022 suggest that the longer the fruits were left in storage, a gradual reduction in rSSC was seen, possibly associated with respiratory carbohydrate use. How much this reduction may affect consumer liking remains to be determined, along with whether there is a minimum rSSC for consumer liking of ‘Jinyan’.

In kiwifruit, the ripe fruit TA seems to influence the consumer liking only when the rSSC is too low, which for ‘Hayward’ has been determined to be <11.6% rSSC [58]. It appears that if the threshold is the same for ‘Jinyan’, the early harvests at ~160–170 DAFB may, in years of low fruit dry matter content, be close to affecting consumer liking. This requires checking to ensure harvest criteria meet quality requirements.

While it is common to use sugar/acid ratio to determine quality in some citrus fruit [59], with the ‘Jinyan’ ripe fruit TA at approximately 1.0 in all seasons, and ripening treatments in 2022, there seemed to be little further information to be gained from these ratios, beyond that available directly from the rSSC values (or estimated from the dry matter at harvest). This is especially true when rSSC values are above any minimum threshold [58] at which TA may affect consumer liking.

Kiwifruits are generally considered to be highly nutritious fruit [60], largely because of the high VitC content. However, the findings from this research suggest that the VitC content may vary depending on the growing season, with a ~10% difference between the 2021 and 2023 fruit. The impact of the environment on VitC content has been reported previously [61] and is consistent with our recent multi-year study [62].

5. Conclusions

It is confirmed that harvest maturity is critical to the good storage performance of ‘Jinyan’ kiwifruit. The good performance includes the fruit not becoming too soft too soon in storage, and retaining firmness at shelf temperatures. A major maturity-related risk identified was chilling sensitivity, which was high in fruit harvested before ~180 DAFB, when fruit were <9% SSC. This gives a clear indication of when fruit should be harvested for long storage. However, if the fruits are left on the vine too long, it appears that rot may be an increasing problem. Finally, based on the rSSC, depending on the season, harvesting before ~170 DAFB may leave the fruit low in rSSC, and the eating quality of the fruit may be slightly less sweet after long storage. Whether these rSSC differences would be detectable by consumers is yet to be determined.

Author Contributions: Conceptualization, W.H., J.B., and C.Z.; methodology, W.H. and F.H.; formal analysis, W.H.; investigation, Q.Z., G.T., and J.Y.; resources, J.Y. and H.L.; writing—original draft preparation, W.H.; writing—review and editing, W.H. and J.B.; funding acquisition, C.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the earmarked fund for CARS (CARS-26) and Hubei Province Funds for Supporting High-Quality Development of Seed Industry (HBZY2023A001-05).

Data Availability Statement: Data are contained within the article.

Acknowledgments: We thank Maryam Alavi at the New Zealand Institute for Bioeconomy Science Limited for statistical advice.

Conflicts of Interest: Author Jeremy Burdon was employed by the company New Zealand Institute for Bioeconomy Science Limited. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

DAFB	Days after full bloom
SSC	Soluble solids content
rSSC	Ripe fruit soluble solids content
DM	Dry matter
TA	Titrateable acidity
VitC	Vitamin C
CI	Chilling injury
SER	Stem-end rot
BR	Body rot
BER	Blossom-end rot

References

- Burdon, J.N.; Wang, R. Postharvest: Fresh fruit harvest, storage and supply. In *Kiwifruit: Botany, Production and Uses*; Richardson, A.C., Burdon, J.N., Ferguson, A.R., Eds.; CABI: Wallingford, UK, 2023; pp. 353–374.
- Burdon, J. Kiwifruit biology: The commercial implications of fruit maturation. *Hortic. Rev.* **2018**, *46*, 385–421. [\[CrossRef\]](#)
- Burdon, J.; McLeod, D.; Lallu, N.; Gamble, J.; Petley, M.; Gunson, A. Consumer evaluation of “Hayward” kiwifruit of different at-harvest dry matter contents. *Postharvest Biol. Technol.* **2004**, *34*, 245–255. [\[CrossRef\]](#)
- Jordan, R.B.; Seelye, R.J. Relationship between taste perception, density and soluble solids concentration in kiwifruit (*Actinidia deliciosa*). *N. Z. J. Crop Hortic. Sci.* **2009**, *37*, 303–317. [\[CrossRef\]](#)
- Cooper, T.; González, L.; Retamales, J. Effects of CPPU on quality and postharvest life of kiwifruit. *Acta Hortic.* **2008**, *796*, 167–171. [\[CrossRef\]](#)
- Wan, H.; Kong, X.; Liu, Y.; Jin, F.; Han, L.; Xu, M.; Li, X.; Li, L.; Yang, J.; Lai, D. Residue analysis and effect of preharvest forchlorfenuron (CPPU) application on quality formation of kiwifruit. *Postharvest Biol. Technol.* **2023**, *195*, 112144. [\[CrossRef\]](#)
- Patterson, K.J.; Currie, M.B. Optimising kiwifruit vine performance for high productivity and superior fruit taste. *Acta Hortic.* **2011**, *913*, 257–268. [\[CrossRef\]](#)
- Mworia, E.G.; Yoshikawa, T.; Salikon, N.; Oda, C.; Asiche, W.O.; Yokotani, N.; Abe, D.; Ushijima, K.; Nakano, R.; Kubo, Y. Low-temperature-modulated fruit ripening is independent of ethylene in ‘Sanuki Gold’ kiwifruit. *J. Exp. Bot.* **2012**, *63*, 963–971. [\[PubMed\]](#)
- Mitalo, O.W.; Tokiwa, S.; Kondo, Y.; Otsuki, T.; Galis, I.; Suezawa, K.; Kataoka, I.; Doan, A.T.; Nakano, R.; Ushijima, K. Low temperature storage stimulates fruit softening and sugar accumulation without ethylene and aroma volatile production in kiwifruit. *Front. Plant Sci.* **2019**, *10*, 888. [\[CrossRef\]](#) [\[PubMed\]](#)
- Burdon, J.; Pidakala, P.; Martin, P.; Billing, D. Softening of ‘Hayward’ kiwifruit on the vine and in storage: The effects of temperature. *Sci. Hortic.* **2017**, *220*, 176–182. [\[CrossRef\]](#)
- Crisosto, C.H.; Zegbe, J.A.; Hasey, J.; Crisosto, G.M. Is dry matter a reliable quality index for ‘Hayward’ kiwifruit? *Acta Hortic.* **2011**, *913*, 531–534. [\[CrossRef\]](#)
- Crisosto, G.; Hasey, J.; Zegbe, J.; Crisosto, C. New quality index based on dry matter and acidity proposed for Hayward kiwifruit. *Calif. Agric.* **2012**, *66*, 70–75. [\[CrossRef\]](#)
- Nishiyama, I. Fruits of the *Actinidia* genus. In *Advances in Food and Nutrition Research*; Academic Press: San Diego, CA, USA, 2007; Volume 52, pp. 293–324.
- Montefiori, M.; McGhie, T.K.; Hallett, I.C.; Costa, G. Changes in pigments and plastid ultrastructure during ripening of green-fleshed and yellow-fleshed kiwifruit. *Sci. Hortic.* **2009**, *119*, 377–387. [\[CrossRef\]](#)
- Gambi, F.; Pilkington, S.M.; McAtee, P.A.; Donati, I.; Schaffer, R.J.; Montefiori, M.; Spinelli, F.; Burdon, J. Fruit of three kiwifruit (*Actinidia chinensis*) cultivars differ in their degreening response to temperature after harvest. *Postharvest Biol. Technol.* **2018**, *141*, 16–23. [\[CrossRef\]](#)
- MacRae, E.; Redgwell, R. Softening in kiwifruit. *Postharvest News Inf.* **1992**, *3*, 49N–52N.
- Burdon, J.; Pidakala, P.; Martin, P.; McAtee, P.A.; Boldingh, H.L.; Hall, A.; Schaffer, R.J. Postharvest performance of the yellow-fleshed ‘Hort16A’ kiwifruit in relation to fruit maturation. *Postharvest Biol. Technol.* **2014**, *92*, 98–106. [\[CrossRef\]](#)
- Choi, H.R.; Tilahun, S.; Park, D.S.; Lee, Y.M.; Choi, J.H.; Baek, M.W.; Jeong, C.S. Harvest time affects quality and storability of kiwifruit (*Actinidia* spp.): Cultivars during long-term cool storage. *Sci. Hortic.* **2019**, *256*, 108523. [\[CrossRef\]](#)
- Costa, G.; Quadretti, R.; Succi, A.; Morigi, M. Influence of harvest time and temperature on fruit quality and storage of kiwifruit (cv Hayward). *Acta Hortic.* **1997**, *444*, 517–522. [\[CrossRef\]](#)
- Gordon Mitchell, F.; Mayer, G.; Biasi, W. Effect of harvest maturity on storage performance of ‘Hayward’ kiwifruit. *Acta Hortic.* **1992**, *297*, 617–626. [\[CrossRef\]](#)
- Kim, H.O.; Hewett, E.W.; Lallu, N. The role of ethylene in kiwifruit softening. *Acta Hortic.* **1999**, *498*, 255–262. [\[CrossRef\]](#)
- Ritenour, M.A.; Crisosto, C.H.; Garner, D.T.; Cheng, G.W.; Zoffoli, J.P. Temperature, length of cold storage and maturity influence the ripening rate of ethylene-preconditioned kiwifruit. *Postharvest Biol. Technol.* **1999**, *15*, 107–115. [\[CrossRef\]](#)
- Richardson, A.C.; Boldingh, H.L.; McAtee, P.A.; Gunaseelan, K.; Luo, Z.; Atkinson, R.G. Fruit development of the diploid kiwifruit, *Actinidia chinensis* ‘Hort16A’. *BMC Plant Biol.* **2011**, *11*, 182. [\[CrossRef\]](#) [\[PubMed\]](#)
- Regiroli, G.; Vriends, P. SmartFreshSM (1-methylcyclopropene) benefits for kiwifruit. *Acta Hortic.* **2007**, *753*, 745–754. [\[CrossRef\]](#)
- Gong, H.J.; Fullerton, C.; Billing, D.; Burdon, J. Retardation of ‘Hayward’ kiwifruit tissue zone softening during storage by 1-methylcyclopropene. *Sci. Hortic.* **2020**, *259*, 108791. [\[CrossRef\]](#)
- Watkins, C.B. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. *Biotechnol. Adv.* **2006**, *24*, 389–409. [\[CrossRef\]](#) [\[PubMed\]](#)
- Watkins, C.B. Pre- and postharvest inhibition of ethylene production and action by 1-MCP and the quality of apples and other horticultural products. *Acta Hortic.* **2016**, *1120*, 1–10. [\[CrossRef\]](#)

28. McDonald, B.; Harman, J. Controlled-atmosphere storage of kiwifruit. I. Effect on fruit firmness and storage life. *Sci. Hortic.* **1982**, *17*, 113–123. [\[CrossRef\]](#)
29. Jabbar, A.; East, A.R. Quantifying the ethylene induced softening and low temperature breakdown of ‘Hayward’ kiwifruit in storage. *Postharvest Biol. Technol.* **2016**, *113*, 87–94. [\[CrossRef\]](#)
30. Defilippi, B.G.; Robledo, P.; Manríquez, D. 1-MCP is an effective tool for reducing detrimental effects of ethylene contamination during kiwifruit storage. *Acta Hortic.* **2011**, *913*, 639–645. [\[CrossRef\]](#)
31. Stec, M.G.; Hodgson, J.A.; Macrae, E.A.; Triggs, C.M. Role of fruit firmness in the sensory evaluation of kiwifruit (*Actinidia deliciosa* cv Hayward). *J. Sci. Food Agric.* **1989**, *47*, 417–433. [\[CrossRef\]](#)
32. Testoni, A. Influence of storage conditions on softening of the columella. *Acta Hortic.* **1992**, *297*, 587–594. [\[CrossRef\]](#)
33. Arpaia, M.; Mitchell, F.; Kader, A. Postharvest physiology and causes of deterioration. In *Kiwifruit Growing and Handling*; ARN Publications, University of California: Davis, CA, USA, 1994; pp. 88–93.
34. Zoffoli, J.P.; Flores, K.; D’Hainaut, D. Effect of ethylene on ripening of kiwifruit stored under controlled or modified atmosphere packaging and treated with 1-methylcyclopropene. *J. Berry Res.* **2016**, *6*, 381–393. [\[CrossRef\]](#)
35. Gwanpua, S.G.; Saeed, M.; Jabbar, A.; Heyes, J. Kiwifruit. In *Postharvest Physiological Disorders in Fruits and Vegetables*; de Freitas, S.T., Pareek, S., Eds.; CRC Press: Boca Raton, FL, USA, 2019; pp. 421–434.
36. Lallu, N.; Searle, A.N.; MacRae, E.A. An investigation of ripening and handling strategies for early season kiwifruit (*Actinidia deliciosa* cv Hayward). *J. Sci. Food Agric.* **1989**, *47*, 387–400. [\[CrossRef\]](#)
37. MacRae, E.A.; Bowen, J.H.; Stec, M.G. Maturation of kiwifruit (*Actinidia deliciosa* cv Hayward) from two orchards: Differences in composition of the tissue zones. *J. Sci. Food Agric.* **1989**, *47*, 401–416. [\[CrossRef\]](#)
38. Burdon, J. Quality aspects of the kiwifruit core. *Acta Hortic.* **2025**, *1431*, 585–590. [\[CrossRef\]](#)
39. Tyson, J.L.; Donati, I.; Everett, K.R. Vine and fruit diseases. In *Kiwifruit: Botany, Production and Uses*; Richardson, A.C., Burdon, J.N., Ferguson, A.R., Eds.; CABI: Wallingford, UK, 2023; pp. 295–316.
40. Manning, M.; Burdon, J.; De Silva, N.; Meier, X.; Pidakala, P.; Punter, M.; Billing, D. Maturity and postharvest temperature management affect rot expression in ‘Hort16A’ kiwifruit. *Postharvest Biol. Technol.* **2016**, *113*, 40–47. [\[CrossRef\]](#)
41. Zhong, C.; Zhang, P.; Han, F.; Li, D. Studies on characterization of fruit development of interspecific hybrid cultivar-‘Jinyan’. *J. Fruit Sci.* **2015**, *32*, 1152–1160.
42. Zhong, C.; Wang, S.; Jiang, Z.; Huang, H. ‘Jinyan’, an interspecific hybrid kiwifruit with brilliant yellow flesh and good storage quality. *HortScience* **2012**, *47*, 1187–1190. [\[CrossRef\]](#)
43. Zhong, C.; Huang, W.; Wang, Z.; Li, L.; Li, D.; Zhang, Q.; Zhao, T.; Zhang, P. The breeding progress and development status of the kiwifruit industry in China. *Acta Hortic.* **2022**, *1332*, 445–454. [\[CrossRef\]](#)
44. Yuan, H.; Zhu, Y.; Li, K.; Yang, D.; Xu, R.; Li, H. Study on postharvest and ripening quality of ‘Jinyan’ kiwifruit with different maturation. *Storage Process* **2020**, *20*, 34–40.
45. Chen, C.; Wang, Y.; Yang, Y.; Yan, Y. Effects of maturity stage on fruit quality and aroma components of ‘Jinyan’ kiwifruit. *Chin. Agric. Sci. Bull.* **2020**, *36*, 28–36.
46. Qian, Z.; Liu, T.; Wang, H.; Qu, H.; Zhong, C.; Huang, H.; Jiang, Y. Effects of harvest stage and storage temperature on quality of ‘Jin Yan’ kiwifruit (*Actinidia chinensis* × *A. eriantha*). *J. Trop. Subtrop. Bot.* **2011**, *19*, 127–134.
47. Wang, Q.; Yang, D.; Zhang, X.; Zhang, X. Growth pattern and storage performance of ‘Jinyan’ kiwi fruits. *Food. Sci.* **2016**, *37*, 129–133.
48. Wang, Z.; Künnemeyer, R.; McGlone, A.; Burdon, J. Potential of Vis-NIR spectroscopy for detection of chilling injury in kiwifruit. *Postharvest Biol. Technol.* **2020**, *164*, 111160. [\[CrossRef\]](#)
49. Huang, W.; Wang, Z.; Yang, J.; Zhang, Q.; Han, F.; Zhang, L.; Zhong, C. Effects of different storage temperatures and humidity on storage performance of kiwifruit ‘Donghong’. *Sci. Technol. Food Ind.* **2025**, *46*, 356–363.
50. Lallu, N. Low temperature breakdown in kiwifruit. *Acta Hortic.* **1997**, *444*, 579–586. [\[CrossRef\]](#)
51. Nardozza, S.; Burdon, J.N. Fruit development: Growth, maturation and ripening. In *Kiwifruit: Botany, Production and Uses*; Richardson, A.C., Burdon, J.N., Ferguson, A.R., Eds.; CABI: Wallingford, UK, 2023; pp. 273–294.
52. Yuan, H.; Martin, P.; Fullerton, C.; Gould, N.; Hall, A.; Burdon, J. Refining the estimation of kiwifruit size from linear fruit dimensions. *Sci. Hortic.* **2020**, *262*, 108878. [\[CrossRef\]](#)
53. McGhie, T.K.; Ainge, G.D. Color in fruit of the genus *Actinidia*: carotenoid and chlorophyll compositions. *J. Agric. Food Chem.* **2002**, *50*, 117–121. [\[PubMed\]](#)
54. Li, D.; Xie, X.; Liu, X.; Cheng, C.; Guo, W.; Zhong, C.; Atak, A. Effects of short-term high temperature on gas exchange in kiwifruits (*Actinidia* spp.). *Biology* **2022**, *11*, 1686. [\[CrossRef\]](#) [\[PubMed\]](#)
55. Lallu, N.; Burdon, J. Experiences with recent postharvest technologies in kiwifruit. *Acta Hortic.* **2007**, *753*, 733–741. [\[CrossRef\]](#)
56. Alavi, M.; Fullerton, C.; Pidakala, P.; Burdon, J. A modelling approach for prediction of chilling injury risk in kiwifruit from softening early in storage. *Acta Hortic.* **2022**, *1332*, 261–268. [\[CrossRef\]](#)

57. Burdon, J.; Pidakala, P.; Martin, P.; Billing, D.; Boldingh, H. Fruit maturation and the soluble solids harvest index for ‘Hayward’ kiwifruit. *Sci. Hortic.* **2016**, *213*, 193–198. [[CrossRef](#)]
58. Crisosto, C.H.; Crisosto, G.M. Understanding consumer acceptance of early harvested ‘Hayward’ kiwifruit. *Postharvest Biol. Technol.* **2001**, *22*, 205–213. [[CrossRef](#)]
59. Asencio, A.D.; Serrano, M.; García-Martínez, S.; Pretel, M.T. Organic acids, sugars, antioxidant activity, sensorial and other fruit characteristics of nine traditional Spanish Citrus fruits. *Eur. Food Res. Technol.* **2018**, *244*, 1497–1508. [[CrossRef](#)]
60. Richardson, D.P.; Ansell, J.; Drummond, L.N. The nutritional and health attributes of kiwifruit: A review. *Eur. J. Nutr.* **2018**, *57*, 2659–2676. [[CrossRef](#)] [[PubMed](#)]
61. Richardson, A.C.; Marsh, K.B.; Boldingh, H.L.; Pickering, A.H.; Bulley, S.M.; Frearson, N.J.; Ferguson, A.R.; Thornber, S.E.; Bolitho, K.M.; MacRae, E.A. High growing temperatures reduce fruit carbohydrate and vitamin C in kiwifruit. *Plant Cell Environ.* **2004**, *27*, 423–435. [[CrossRef](#)]
62. Huang, W.; Han, F.; Yang, J.; Ran, X.; Shen, S.; Zhang, Q.; Ye, N.; Lu, H.; Zhong, C. Multi-year evaluation of fruit quality diversity, stability, and climatic drivers across a diverse *Actinidia* germplasm collection. *Hortic. Adv.* **2026**, *in press*.

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