



Changes in Volatile Compounds of 'Hayward' Kiwifruit During Storage

Ömer Faruk BİLGİN^{*}

Department of Horticulture, Faculty of Agriculture, Siirt University, Siirt, Türkiye,
<https://orcid.org/0000-0002-9300-1867>
✉: obilgin@siirt.edu.tr

ABSTRACT

The aim of this study was to compare the aroma profiles of fresh 'Hayward' kiwifruit during different cold storage periods, using the SPME method in combination with gas chromatography-mass spectrometry (GC-MS). Cold storage duration significantly influenced the accumulation of volatile and major aroma compounds. After three months, 1-hexanol, a main aroma component, increased by 66.7% before exhibiting a slight decline. The concentration of 2-hexen-1-ol (E) increased by 170% in the third month, then returned to nearly its initial level by the fifth month. Conversely, 2-hexenal steadily declined, decreasing by nearly 81% by the fifth month. Similarly, 3-hexen-1-ol (Z) increased by approximately 100% after three months, but subsequently decreased by 75% in the fifth month. Notably, ethanol and acetic acid ethyl ester, initially undetected, rapidly accumulated during storage, reaching 4.38% in the third month and 22.40% in the fifth month. Total alcohol content increased steadily, rising from 6.99% to 15.85% and further to 48.10%. Total esters showed the most significant increase, rising from 0.99% to 31.49% by month five. In contrast, total aldehyde content decreased from 80.56% (0M) to 28.19% (5M). Ketones and terpenes, initially undetected, emerged during storage, reaching 0.30% and 24.07% by month five, respectively. These results indicate significant alterations in the aroma profiles, potentially impacting the aroma quality of kiwifruits during extended storage.

Horticulture

Research Article

Article History

Received : 10.10.2024
Accepted : 31.05.2025

Keywords

Storage Durations
Volatile compounds
GC-MS
SPME
Kiwi

'Hayward' Kivi Çeşidinin Aroma Bileşiklerinde Depolama Sırasında Meydana Gelen Değişimler

ÖZET

Bu çalışmanın amacı, 'Hayward' kivi çeşidi meyvelerinin farklı soğuk depolama süreleri boyunca aroma profillerini karşılaştırmaktır. Çalışmada, GC-MS (Gaz Kromatografisi-Kütle Spektrometresi) ile birlikte SPME yöntemi kullanılmıştır. Soğuk depolama süresi, uçucu bileşiklerin ve temel aroma bileşiklerinin birikimini önemli ölçüde etkilemiştir. Üçüncü aydan sonra, başlıca aroma bileşenlerinden biri olan 1-hexanol, %66,7 oranında artış göstermiş, ardından hafif bir düşüş kaydetmiştir. Benzer şekilde, 2-hexen-1-ol (E) üçüncü ayda %170 oranında artış göstermiş, ancak beşinci ayda başlangıç seviyelerine yakın bir düzeye gerilemiştir. Buna karşılık, 2-hexenal beşinci aya kadar sürekli bir düşüş göstermiş ve toplamda %81 oranında azalma kaydetmiştir. Aynı şekilde, 3-hexen-1-ol (Z) üçüncü aydan sonra yaklaşık %100 oranında artmış, ancak beşinci ayda %75 oranında düşüş göstermiştir. Başlangıçta tespit edilemeyen etanol ve etil asetik, depolama sırasında hızla birikmiş ve üçüncü ayda sırasıyla %4.38 ve beşinci ayda %22.40 seviyelerine ulaşmıştır. Toplam alkol içeriği istikrarlı artış göstererek, %6.99'dan üçüncü ayda %15.85'e ve beşinci ayda %48.10'a yükselmiştir. Toplam ester miktarı ise en belirgin artışı göstererek, beşinci ayda %0.99'dan %31.49'a yükselmiştir. Buna karşılık, toplam aldehit miktarı depolama süresince %80.56'dan (0.ay) seviyesinden %28.19'a (5.ay) düşmüştür. Başlangıçta tespit edilemeyen ketonlar ve terpenler, depolama sırasında ortaya çıkmış ve sırasıyla üçüncü ayda %0,30 ve beşinci

Bahçe Bitkileri

Araştırma Makalesi

Makale Tarihi

Geliş Tarihi : 10.10.2024
Kabul Tarihi : 31.05.2025

Anahtar Kelimeler

Depolama süreleri
Gc/ms
Aroma bileşenleri
SPME
Kiwi

ayda ise %24,07 seviyelerine ulaşmıştır. Bu sonuçlar, aroma profillerinde önemli değişikliklere işaret etmekte ve kivi meyvelerinin uzun süreli depolama sırasında aroma kalitesini önemli ölçüde etkileyebileceğini ortaya koymuştur.

Atf İçin: Bilgin, Ö.F (2026). 'Hayward' Kivi Çeşidinin Aroma Bileşiklerinde Depolama Sırasında Meydana Gelen Değişimler.. *KSÜ Tarım ve Doğa Derg* 29 (1), 51-61. DOI: 10.18016/ksutarimdog.vi.1564516.

To Cite: Bilgin, Ö.F (2026). Changes in Volatile Compounds of 'Hayward' Kiwifruit During Storag.. *KSU J. Agric Nat* 29 (1), 51-61. DOI: 10.18016/ksutarimdog.vi.1564516.

INTRODUCTION

The native *Actinidia* genus in China comprises over 70 species; however, only a few are commercially significant, primarily *Actinidia deliciosa* and *Actinidia chinensis*. Since the Tang Dynasty (7th century A.D.), kiwifruit and the *Actinidia* genus have been referred to in China as 'mihoutao' or 'monkey peach'. (Huang & Ferguson, 2006). However, kiwifruit has recently gained significant international commercial importance (Ferguson, 2014). The first commercial plantation of *A. deliciosa* was established in New Zealand in 1930 (Trugo & Finglas, 2003). Kiwifruit is New Zealand's second-largest agricultural exporter after wine. According to Trugo & Finglas (2003), New Zealand exported over 360,000 tonnes of kiwifruit annually, with the 'Hayward' variety accounting for 80% of these exports. The 'Hayward' variety's robust post-harvest performance, allowing storage near 0 °C for extended periods, significantly contributes to kiwifruit's success in international trade. *Actinidia chinensis*, commonly known as kiwifruit, is a highly valuable fruit originating in China that has gained widespread global popularity (Ferguson, 2014). Its flavor and nutritional attributes, including high vitamin C content and health-promoting properties, are highly valued by consumers (Collins et al., 2001; Rassam & Laing, 2005). Kiwifruit flavor arises from a complex interplay of volatile molecules, with aroma serving as a primary contributor to the fruit's overall flavor, acidity, and sweetness. Therefore, effective and efficient methods for analyzing these volatile compounds are crucial for understanding the fruit's aromatic characteristics. Because gas chromatography-mass spectrometry (GC-MS). can simultaneously separate and identify numerous volatile components, it is commonly employed to analyze aroma compounds in kiwifruits (Biniecka & Caroli, 2011). Nevertheless, prior to GC-MC analysis, it is essential to separate the volatile compounds from the complex sample matrix. Methods frequently employed to isolate volatile compounds include solvent extraction (Jordán et al., 2002), distillation (Takeoka et al., 1986; Young et al., 1983), static or dynamic headspace (SH or DH) (Dijksterhuis & Piggott, 2000; Friel et al., 2007), and solid-phase microextraction (SPME) (Günther et al., 2011). These methods typically depend on the volatility or solubility of the volatile compounds. The original purpose of solid-phase microextraction (SPME) was to extract organic molecules from aqueous solutions using a solvent-free, simple, rapid, reproducible, and cost-effective approach (Arthur & Pawliszyn, 1990; McDonnell & Pawliszyn, 1990). SPME has found substantial application across various aspects of analytical chemistry, including the extraction and concentration of trace volatile compounds in fresh and fruit juice (Reid et al., 2004). More recently, SPME has been applied to the analysis of volatile compounds in various matrices, including foods (Ligor et al., 2004), beverages (Lv et al., 2024; Panighel & Flamini, 2014), and fruits such as mulberry (Burgut et al., 2023), grape, raspberry, apples (Vrhovsek et al., 2014), strawberry (Oz et al., 2016), and sour cherry (Sun et al., 2012).

There is limited quantitative data on how the volatile compounds of kiwifruit change as it ripens. This study aimed to identify the headspace volatile flavor compounds of kiwifruit using SPME in conjunction with GC-MS and to investigate the changing profile of these volatile compounds during storage and ripening.

MATERIAL and METHOD

The commercially significant variety is *Actinidia deliciosa* (A. Chev.) C. F. Liang et A. R. Ferguson var. *deliciosa* 'Hayward,' which possesses the highest value globally. Hayward has established itself as the industry benchmark owing to several attributes of the fruit, including substantial size, excellent flavor, extended storage capability, and relatively reduced vigor (Ferguson & Bollard, 1990), despite its tendency to yield fewer fruits than other cultivars (Sale & Lyford, 1990). On December 12, 2023, kiwifruit (*Actinidia deliciosa* cv. 'Hayward') was harvested in Samsun city, which is located in the northern region of Turkey. At the time of harvest, the fruit exhibited a hardness of approximately 8 kgf, whereas the soluble solid content (SSC) was approximately 8%.

Design of Experiment

To determine how storage duration affected taste and quality, the aroma profiles of kiwifruit samples stored for zero, three, and five months were examined. Twelve fruits were selected for each storage period to ensure consistency in size, freshness, and diversity. Analyses were conducted at three intervals to identify variations in the aroma components of the 'Harward' kiwi variety.

Storage Conditions

Approximately 250 grams of kiwifruit were stored in containers wrapped with polyethylene, which were placed inside regular modular bulk containers. This setup helped minimize moisture loss while providing adequate ventilation. The relative humidity was maintained between 88-90%, and the storage temperature was kept at 2-4°C to slow down ripening and preserve fruit quality.

Sampling Method for Headspace SPME-GC-MS Analyzing

Three containers were chosen for SPME-GC-MS analysis for each of the three storage durations (stored for zero, three, and five months, respectively). The results of this analysis were then compared across the three groups to determine how the volatile flavor components in kiwifruit changed throughout storage.

The fruits were cut into four sections, and the peel was discarded. After peeling, 12 kiwifruits were sliced into small pieces and mixed (Wan et al., 1999). One gram of the sample was taken from the mixture for one replicate. Three replicates were used for each experiment. Randomly selected pieces were added to a 500 mL round-bottom flask.

GC-MS Analyzing

After weighing one gram of homogenized kiwifruit, 1 ml of CaCl₂ was added to a headspace vial, and the mixture was incubated for thirty minutes at 40°C. The SPME was outfitted with a 30 mm fused silica fiber coated with polydimethylsiloxane–divinylbenzene. The septum was used to enter the fiber into the sample container, and it was left in the headspace for 30 min. After adsorption on the SPME fiber, volatile chemicals were thermally desorbed in the GC injector port and subsequently separated on the GC column. One minute was spent on desorption. Helium was employed as the carrier gas at a linear rate of 1.0 mL/min⁻¹ for the GC-MS analysis, which was carried out in a GC-MS, Shimadzu GC-2010 Plus HP-An Innowax Agilent column (30 m × 0.25 mm i.d., 0.25 μm thickness) (Shimadzu, Kyoto, Japan). Six minutes were spent holding column temperature at 40 °C. After that, it was raised to 260 °C at a rate of 5 °Cmin⁻¹, and kept there for 40 min. The temperatures of the detector and injection port (splitless mode) were 220 and 260 °C, respectively. Helium was used as the carrier gas (column flow rate: 1 mL/min⁻¹). The mass spectrum (MS) was obtained at 70 eV, covering a mass range of m/z 30–400. A library search was conducted using commercial databases, including Wiley, NIST, and Flavor GC-MS Libraries. The mass spectra were further compared to reference compounds and validated with retention indices from published sources. The relative percentage of the separated volatile compounds was determined from total ion chromatograms. The results represent the relative area (%), calculated by dividing the peak area of each compound by the total peak area and multiplying by 100.

Statistical Methods

Volatile compounds were analyzed in triplicate, and the results are presented as means (Table 1). The total components and common volatile compounds across three storage conditions were determined and analyzed by analysis of variance (ANOVA) (MATLAB 2024 (Katsikis, V. (2012)); The MathWorks, Inc., Natick, Massachusetts, USA, $p < 0.01$, using Kolmogorov procedure). Multiple comparisons of the storage means were performed using Tukey's multiple range test (MATLAB 2024; The MathWorks, Inc., Natick, Massachusetts, USA, $p < 0.01$). PCA analysis and biplot visualization were performed in Python using scikit-learn, matplotlib, and seaborn, following established methods for projecting sample scores and compound loadings (Statistics Globe, 2022).

RESULTS and DISCUSSION

Our study identified and compared the volatile compounds in 'Hayward' kiwifruit across three storage durations. Typical headspace SPME-GC-MS profiles of kiwifruit volatiles at zero (0M), three (3M), and five (5M) months of storage are presented in Tables 1 and 2. At one month after harvest (0M), 23 volatile compounds were identified, comprising six alcohols, three aldehydes, seven terpenes, three acids, two ketones, and two esters (Table 1 and Table 2). After three months of storage (3M), 24 volatile compounds were identified, including six alcohols, three aldehydes, seven terpenes, two ketones, and six esters (Table 1 and Table 2). By five months of storage (5M), the number increased to 32 volatile compounds, consisting of seven alcohols, two aldehydes, 13 terpenes, two ketones, and eight esters (Table 1 and Table 2). While Table 1 and 2 indicates similar chemical compositions of volatile compounds across the three storage durations, significant differences were observed in their relative contents. Specifically, the relative abundance of most compounds varied considerably with storage duration. Six volatile components in Figure 1 exhibited significant differences. ($p < 0.01$) in their relative contents across the three storage periods. Among the identified compounds, 1-hexanol, 3-hexen-1-ol (Z), 2-hexen-1-ol (E), ethanol, acetic acid ethyl ester, and 2-hexenal were consistently found in kiwifruit during storage. Notably, 2-hexenal was the major volatile compound at one month of storage, comprising 78.54% of total volatiles, but its concentration significantly decreased to 65.9% at three months and 15% at five months. Conversely, ethanol, which was nearly absent at one

month (0%) and low at three months (2.78%), became a dominant volatile compound after five months of storage, reaching a relative content (RC) of 22.4%. C6 alcohols (1-hexanol, 3-hexen-1-ol (Z), 2-hexen-1-ol (E), and (E)-2-hexenol) and C6 aldehydes (hexanal) were consistently prevalent across all storage stages. Shiota (1982) and Young et al. (1983) were the first to publish results on volatile compounds in kiwifruit. Using a distillation extraction method, they identified ethyl butanoate, (E)-2-hexenal, (E)-2-hexenol, methyl benzoate, and ethyl benzoate as the primary contributors to kiwifruit aroma (Shiota, 1982; Young et al., 1983). Garcia et al., (2012) reported the identification of over 80 volatile compounds in kiwifruit, with key components including methyl and ethyl butanoate, (Z) and (E)-hexenal, hexanal, (Z) and (E)-3-hexenol, and methyl benzoate. Zhang et al., (2016) identified three major volatile compounds, such as acetaldehyde, ethanol, and furfural, in several kiwifruit varieties. (E)-2-hexenal, as the most abundant compound, was determined by some researchers (Frank et al., 2007; Takeoka et al., 1986) in ripe kiwifruits. However, it is noteworthy that (E)-2-hexenal was absent in other studies (Bartley & Schwede, 1989; Paterson et al., 1991), highlighting the potential variability in volatile profiles due to factors such as extraction methods. The aroma of eating ripe 'Hayward' kiwifruit is characterized as grassy and sulfurous, along with a melon-like and sweet candy flavor, forming its distinctive sensory profile (Wang et al., 2011). Another study by Starowicz et al., (2022) found that volatile compounds such as methyl and ethyl butanoate, hexanal, (E)-2-hexenal, 1-hexanol, (E)-2-hexen-1-ol, and (Z/E)-3-hexen-1-ol were the main contributors to kiwifruit aroma. These results are comparable with those of the present study. These compounds impart strong notes

Table 1. Acids, Alcohols, and Aldehydes profiles of freshly harvested 'Hayward' kiwi-fruit at different storage stages (0M, 3M, 5M, N.D. = not detected)

Çizelge 1. Taze hasat edilmiş 'Hayward' kivi meyvesinin farklı depolama aşamalarındaki (0M, 3M, 5M) asit, alkol ve aldehit profilleri. (N.D = tespit edilememiştir)

R.T	Compound Class	Compound Name	0m (%)	3m (%)	5m (%)
2.531	Acids	2-Methyl Butyric Acid	N.D	0.93	N.D
12.689	Acids	Acetic Acid (Cas)	0.26	n.d	N.D
3.485	Acids	Carbonic Acid, Diethyl Ester (Cas)	N.D	0.46	N.D
23.538	Acids	Hexanoic Acid (Cas)	0.13	N.D	N.D
30.909	Acids	Trans 2-Hexenoic Acid	0.27	N.D	N.D
18.019	Acids	Beta-Bisabolene (Cas)	N.D	0.31	N.D
9.979	Alcohols	1-Hexanol (Cas)	0.18	0.3	0.26
18.015	Alcohols	2 Ethyl Hexanol	0.67	N.D	N.D
10.579	Alcohols	2-Hexen-1-Ol	2.26	N.D	N.D
11.970	Alcohols	2-Hexen-1-Ol, (E)- (Cas)	2.94	7.94	2.91
10.514	Alcohols	2-Hexen-1-Ol, (Z)- (Cas)	N.D	0.84	N.D
9.484	Alcohols	3-Hexen-1-Ol, (E)- (Cas)	N.D	0.1	0.13
1.541	Alcohols	3-Hexen-1-Ol, (Z)- (Cas)	0.26	0.52	0.13
1.527	Alcohols	Ethanol	N.D	0.57	1.43
1.543	Alcohols	Ethanol (Cas)	N.D	2.78	22.4
1.538	Alcohols	Iso Amyl Alcohol	N.D	N.D	1.03
9.215	Alcohols	Isooctanols	0.51	N.D	N.D
5.056	Alcohols	Trans-Geraniol	0.16	N.D	N.D
10.510	Aldehydes	2,4-Hexadienal (Cas)	0.19	N.D	N.D
1.547	Aldehydes	2-Hexenal (Cas)	78.54	65.63	15
0.78	Aldehydes	Acetaldehyde (Cas)	N.D	0.02	N.D
1.546	Aldehydes	Hexanal	N.D	N.D	0.33

Table 2. Esters, Ketones and Terpenes profiles of freshly harvested 'Hayward' kiwi-fruit at different storage stages (0M, 3M, 5M, . N.D = not detected)

Çizelge 2. Taze hasat edilmiş 'Hayward' kivi meyvesinin farklı depolama aşamalarındaki (0M, 3M, 5M) ester, keton ve terpenes profilleri. (N.D = tespit edilememiştir)

R.T	Compound Class	Compound Name	0m (%)	3m (%)	5m (%)
1.031	Esters	2-Propanone (Cas)	0.34	N.D	N.D
15.174	Esters	4-Terpinyl Acetate	N.D	1.09	20.1
1.569	Esters	Acetic Acid, Ethyl Ester (Cas)	N.D	0.41	4.38
16.660	Esters	Benzoic Acid, Ethyl Ester	N.D	1.07	N.D
1.573	Esters	Butanoic Acid, 2-Methyl-, Ethyl Ester	N.D	N.D	1.92
2.354	Esters	Butanoic Acid, Ethyl Ester	N.D	5.01	1.83
1.566	Esters	Carbonic Acid, Diethyl Ester	N.D	N.D	0.45
1.568	Esters	Formic Acid, Hexyl Ester	N.D	N.D	1.14
21.135	Esters	Phenylacetate <Hexyl->	0.62	N.D	N.D
1.643	Esters	Propanoic Acid, 2-Methyl-, Ethyl Ester	N.D	0.26	N.D
1.596	Esters	Propanoic Acid, Ethyl Ester	N.D	0.47	0.86
1.571	Esters	Propanoic Acid,2-Methyl-, Ethyl Ester	N.D	N.D	0.81
18.226	Ketones	.Beta.-Bisabolene (Cas)	0.21	0.31	0.34
23.732	Ketones	2,2-Dimethyl-3 Heptanone	0.18	N.D	N.D
1.567	Ketones	2-Propanone, 1-Hydroxy	N.D	0.64	0.3
1.55	Terpenes	(+)-2-Carene	N.D	N.D	0.99
5.380	Terpenes	(+)-Limonene	4.69	N.D	0.46
2.021	Terpenes	.Alpha.-Pinene, (-)	2.28	1.56	0.15
4.100	Terpenes	.Delta.3-Carene	0.25	0.55	0.17
3.238	Terpenes	2-.Beta.-Pinene	0.24	0.71	N.D
1.554	Terpenes	Alpha. Terpinene	N.D	N.D	2.04
1.561	Terpenes	Alpha.-Pinene, (-)	2.28	1.56	0.15
1.559	Terpenes	Alpha.-Terpinolene	N.D	N.D	1.04
1.558	Terpenes	Benzene,1-Methyl-4-(1-Methylethyl)(Cas)	N.D	N.D	4.96
1.553	Terpenes	Alpha-Terpinene	N.D	N.D	3.59
1.562	Terpenes	Beta.-Bisabolene (Cas)	0.21	0.31	0.34
1.56	Terpenes	Beta.-Phellandrene	N.D	N.D	0.22
1.556	Terpenes	Gamma-Terpinene	N.D	N.D	9.99
5.155	Terpenes	L-Limonene	0.18	0.10	0.12
6.895	Terpenes	M-Cymene	N.D	0.29	N.D

described as 'leaf-like,' 'hay,' and 'old-cut grass,' with the Z-isomer specifically contributing a 'green note' (Young et al., 1983). Jordán et al. (2002) and Zhao et al. (2020) linked this set of volatiles, particularly high levels of hexanal and 2-hexenal in 'Hayward,' to the fruit's characteristic herbal, strawberry, green, cherry, and grassy flavors. We found statistically significant differences in the concentrations of major volatile compounds across different storage conditions (Figure 1, $p < 0.01$). Specifically, 2-hexenal levels in fruits after five months of storage were significantly lower than those observed after one and three months. Conversely, ethanol concentrations increased with storage duration; for instance, ethanol was significantly higher (22%) after five months of storage compared to other durations (Figure 1, $p < 0.01$). Ethanol in fruits is produced by the enzyme alcohol dehydrogenase. Fruits produce ethanol during ripening on the tree by activating anaerobic metabolic pathways that generate aroma compounds and other metabolites (Pesis, 2005). Climacteric and non-climacteric fruits produce significant amounts of acetic acid and ethanol. This production primarily depends on the genetic

characteristics and storage conditions. The capacity of various fruits to produce acetic acid and ethanol and to tolerate anaerobiosis also has a genetic basis. The oxygen level at which fermentation begins and ethanol accumulates is referred to as the Pasteur point (Fidler, 1968), lower oxygen limit (LOL) (Beaudry, 1993), or fermentation induction point (FID) (Petracek et al., 2002). These parameters vary among different fruit types. Deciduous fruits are generally more tolerant of low-oxygen storage conditions than those from subtropical or tropical regions. However, considerable variation still exists among fruits. For example, in apples, differences in peel anatomy between 'Delicious' and 'Granny Smith' varieties may lead to variations in gas exchange and accumulation of anaerobic metabolites under different coatings (Bai et al., 2003). Several researchers have observed that in apples, factors such as intercellular air space volume, peel porosity, and resistance to gas diffusion influence the development of CO₂ injury during storage (Watkins et al., 1997). Argenta et al., (2002) reported that 'Fuji' apples with smaller intercellular air spaces were more prone to watercore in their tissue, and the severity of watercore in their tissue, and the severity of watercore was associated with higher levels of internal acetic acid and ethanol. In citrus fruits, which are sensitive to low oxygen storage, 'Valencia' oranges produced significantly more ethanol than 'Marsh Seedless' grapefruit at 20 °C (Norman & Houck, 1977). Furthermore, ethanol accumulation has been observed in various fruits, with levels increasing under diverse storage conditions. Examples include oranges (Bruemmer & Roe, 1985), apples (Nichols & Patterson, 1987), pears (Chervin et al., 1999), lychee (Pesis, 2005), peaches and nectarines (Lavilla et al., 2000), strawberries (Pesis & Avissar, 1990), mango (Baldwin et al., 1999), and guava (McGuire & Hallman, 1995). Acetic acid and ethyl ester (CAS) levels were significantly higher after five months of storage than after earlier storage periods (Figure 1, $p < 0.01$). Additionally, 1-Hexanol (CAS) and 3-Hexen-1-ol, (Z)-(CAS) levels increased in fruits after three months of storage but decreased after five months.

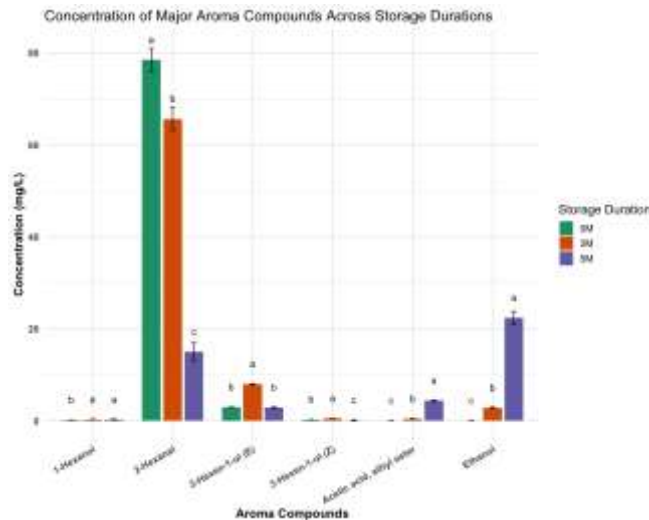


Figure 1. Analysis of variance table showing the effect of storage duration on aroma compound concentration. Storage durations included OM (original/month 0), 3M (three months), and 5M (five months). Se = standard error. The p-values indicate the level of statistical significance.

Şekil 1. Depolama sürelerinin kiwi meyvesinde aroma içeriğine etkilerine ait varyans tablosu (OM, 3M = Üç ay, 5M = beş ay). Her bar üç tekrardan elde edilen ortalamayı ve standart hatasını temsil etmektedir. Farklı harfler uygulamalar arasındaki önemli farklılıkları göstermektedir (Tukey's HSD, $p < 0.01$).

This PCA biplot visualizes the relationships between different storage durations (0M, 3M, 5M) and the mean values of various aroma compound classes (total aldehydes, total ketones, total esters, total alcohols, total terpenes) in kiwifruit (Figure 2). PC1 accounts for a substantial 80.5% of the total variance, while PC2 explains an additional 19.4%. This indicates that PC1 is the primary driver of variation in the aroma profiles, and the two components together capture almost all (99.9%) of the variability in the data. Blue points (OM) are clustered on the far left side of the biplot, primarily along the negative end of PC1 (Figure 2).

This suggests that the aroma profile at the initial storage stage (0 months) is distinct from later stages. Teal points (3M) are positioned in the upper-left quadrant, showing some separation from 0M samples, mainly along PC2. This indicates a shift in aroma profile after three months of storage. Green points (5M) are clustered on the far right side of the biplot, along the positive end of PC1. This clearly demonstrates a significant change in the aroma profile after five months of storage, distinctly different from both 0M and 3M. The vectors (red arrows) represent the aroma compound classes, and their direction and length indicate their influence on the principal components and their correlation with the samples. The vector for total aldehydes points strongly towards the negative end of PC1,

aligning with the 0M samples. This suggests that higher levels of total aldehydes are characteristic of kiwifruit at the initial storage stage (0 months). Total esters, total alcohols, and total terpenes vectors point towards the positive end of PC1, aligning with the 5M samples. This indicates that these compound classes are positively correlated with each other and are more abundant in kiwifruit after five months of storage. The longer length of these vectors also suggests a strong influence on the separation observed along PC1. The vector for total ketones points strongly upwards along the positive end of PC2. This indicates that total ketones contribute significantly to the variation explained by PC2, and their levels might be higher in samples that are positioned higher on the PC2 axis (e.g., some 3M samples). The PCA representation strongly supports the conclusion that cold storage significantly alters the volatile compound composition, thereby impacting the overall aroma quality of the kiwifruit (Figure 2).

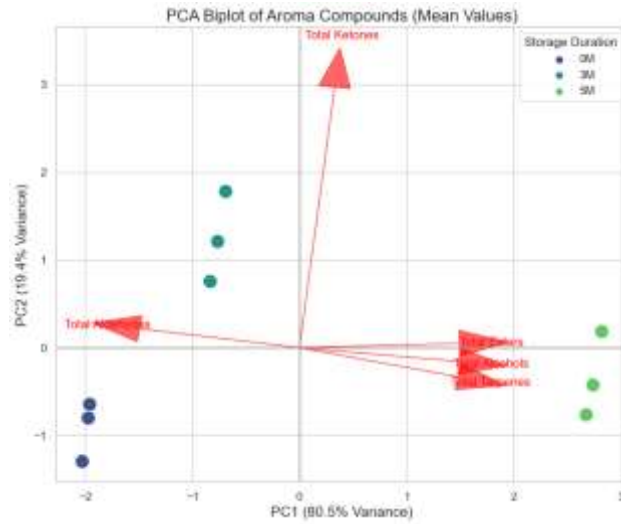


Figure 2. PCA Biplot of Total Aroma Compounds visually represents the relationships between kiwifruit samples at various storage durations and the contribution of different aroma compound classes to their overall aroma profiles.

Şekil 2. PCA , farklı depolama sürelerindeki kivi meyvesi örnekleri arasındaki ilişkileri ve çeşitli aroma bileşeni sınıflarının genel aroma profiline katkılarını görünümü

We found significant differences in the total alcohol, aldehyde, ester, ketone, and terpene contents among the three storage conditions (Figure 3, $p < 0.01$). The concentrations of total alcohols, terpenes, and esters increased as the storage duration increased, while total aldehydes decreased over the same period (Figure 3). These results were similar to those reported by Wan et al. (1999) on kiwifruit during storage, but differed from studies by Pfannhauser et al. (1990) concerning different ripening stages of kiwifruit. These discrepancies may be attributed to the use of disparate ripening methodologies. C6 aldehydes and C6 alcohols were the main sources of the fresh and grassy kiwifruit aroma, according to Cozzolino et al. (2020). Cozzolino et al., (2020) reported that volatile production increased in both 'Hayward' and 'Hort16A' kiwifruit as the fruit softened. Similarly, Young et al. (1983) found comparable results for 'Hayward' fruit, and our findings were consistent with these observations. Wang et al., (2011) specifically demonstrated that the concentration of aldehyde compounds decreased, while the concentration of esters increased in overripe fruit. Additionally, several researchers studying the same cultivars found that the concentration of alcohol increased as the fruit softened. Wang et al., (2011) also noted that while aldehyde levels remained relatively stable during ripening, their proportion of total volatiles declined due to the increase in esters and alcohols. However, these findings contradict our results. Previous studies have shown that ester concentrations tend to increase with fruit ripening (Paterson et al., 1991; Young et al., 1983). These results were consistent with our results. Our study found that storage duration significantly influenced the concentration of volatile compounds. Similar findings were reported by Pelayo et al. (2003), who demonstrated that the storage temperature affects the production of aroma compounds during strawberry storage. In addition to temperature, factors such as maturity, storage atmosphere, and light have been shown to affect the production of volatile aroma components in strawberries (Forney et al., 2000). To maintain optimal aroma quality and minimize undesirable volatile compound changes, kiwifruit storage duration should be carefully managed, particularly to control the accumulation of ethanol and esters and the decline of aldehydes.

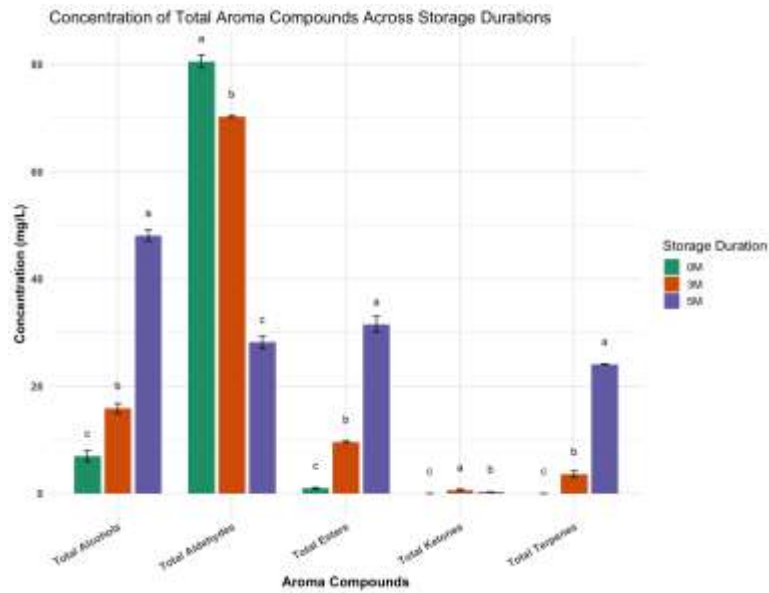


Figure 3. Variations in the concentrations of total alcohols, aldehydes, esters, ketones, and terpenes in kiwifruit volatiles across three storage periods. Each bar represents the mean of three replicates, with standard error shown at the top of each bar. Different letters indicate statistically significant differences between storage conditions (Tukey's HSD, $p \leq 0.05$). OM: Zero month, 3M: Three months of storage, 5M: Five months of storage.

Şekil 3. Üç depolama süresi boyunca kivi uçucu maddelerindeki toplam alkol, aldehit, ester, keton ve terpen konsantrasyonlarına ait varyans tablosu (her bir bar üç tekrerrürün ortalamasını ve Tekerrürlerin standart sapması göstermektedir. Farklı harfler depolama koşulları arasındaki önemli farklılıkları göstermektedir (Tukey's HSD, $p \leq .01$). OM : İlk ay, 3M : 3.ay, 5M : 5. Ay

CONCLUSION

This study demonstrated that the storage duration of kiwifruits significantly affected their volatile components. Overall, volatile concentrations generally increased with extended storage times. The major volatile compounds identified in the profile of 'Hayward' kiwifruit were 1-Hexanol, 3-Hexen-1-ol (Z), 2-Hexen-1-ol (E), and 2-Hexenal at all storage stages. The concentration of ethanol significantly increased as storage duration increased, while acetic acid ethyl ester (CAS) levels were notably higher after five months of storage compared to earlier periods. Additionally, 1-Hexanol (CAS) and 3-Hexen-1-ol (Z)-(CAS) increased after three months of storage but decreased after five months. While the total aldehydes decreased with longer storage, the total alcohols, terpenes, and acids increased. Aldehydes, alcohols, and esters were the primary contributors to the volatile profile of 'Hayward' kiwifruit for all storage durations.

Author Contributions

The author was solely responsible for the conceptualization, methodology, data analysis, interpretation, and manuscript preparation.

Statement of Conflict of Interest

The author declares that there is no conflict of interest.

REFERENCES

- Argenta, L. C., Fan, X., & Mattheis, J. P. (2002). Responses of 'Fuji' apples to short and long duration exposure to elevated CO₂ concentration. *Postharvest Biology and Technology*, 24(1), 13–24. [https://doi.org/10.1016/S0925-5214\(01\)00120-X](https://doi.org/10.1016/S0925-5214(01)00120-X)
- Arthur, C. L., & Pawliszyn, J. (1990). Solid phase microextraction with thermal desorption using fused silica optical fibers. *Analytical Chemistry*, 62(19), 2145–2148.
- Bai, J., Hagenmaier, R. D., & Baldwin, E. A. (2003). Coating selection for 'Delicious' and other apples. *Postharvest Biology and Technology*, 28(3), 381–390. [https://doi.org/10.1016/S0925-5214\(02\)00201-6](https://doi.org/10.1016/S0925-5214(02)00201-6)
- Baldwin, E. A., Burns, J. K., Kazokas, W., Brecht, J. K., Hagenmaier, R. D., Bender, R. J., & Pesis, E. (1999). Effect of two edible coatings with different permeability characteristics on mango (*Mangifera indica* L.) ripening during storage. *Postharvest Biology and Technology*, 17(3), 215–226. <https://doi.org/10.1016/S0925->

5214(99)00053-8

- Bartley, J. P., & Schwede, A. M. (1989). Production of volatile compounds in ripening kiwi fruit (*Actinidia chinensis*). *Journal of Agricultural and Food Chemistry*, 37(4), 1023–1025.
- Beaudry, R. M. (1993). Effect of carbon dioxide partial pressure on blueberry fruit respiration and respiratory quotient. *Postharvest Biology and Technology*, 3(3), 249–258. [https://doi.org/10.1016/0925-5214\(93\)90060-G](https://doi.org/10.1016/0925-5214(93)90060-G)
- Biniecka, M., & Caroli, S. (2011). Analytical methods for the quantification of volatile aromatic compounds. *TrAC Trends in Analytical Chemistry*, 30(11), 1756–1770. <https://doi.org/10.1016/j.trac.2011.06.015>
- Bruemmer, J. H., & Roe, B. (1985). Pyruvate dehydrogenase activity during ripening of hamlin oranges. *Phytochemistry*, 24(9), 2105–2106. [https://doi.org/10.1016/S0031-9422\(00\)83131-3](https://doi.org/10.1016/S0031-9422(00)83131-3)
- Burgut, A., Ada, M., Bilgin, Ö. F., & Kafkas, E. (2023). Aroma compounds and chemical content of four selected mulberry genotypes using gas chromatography (gc-ms) in Turkey. *International Journal of Agriculture Forestry and Life Sciences*, 7(2), 30–32.
- Chervin, C., Truett, J. K., & Speirs, J. (1999). Alcohol dehydrogenase expression and alcohol production during pear ripening. *Journal of the American Society for Horticultural Science*, 124 (1), 1999, 71-75
- Collins, B. H., Horská, A., Hotten, P. M., Riddoch, C., & Collins, A. R. (2001). Kiwifruit Protects Against Oxidative DNA Damage in Human Cells and In Vitro. *Nutrition and Cancer*, 39(1), 148–153. https://doi.org/10.1207/S15327914nc391_20
- Cozzolino, R., De Giulio, B., Petriccione, M., Martignetti, A., Malorni, L., Zampella, L., Laurino, C., & Pellicano, M. (2020). Comparative analysis of volatile metabolites, quality and sensory attributes of *Actinidia chinensis* fruit. *Food Chemistry*, 316, 126340.
- Dijksterhuis, G. B., & Piggott, J. R. (2000). Dynamic methods of sensory analysis. *Trends in Food Science & Technology*, 11(8), 284–290.
- Ferguson, A. R. (2014). Kiwifruit in the world-2014. In *VIII International Symposium on Kiwifruit 1096* (pp. 33-46).
- Ferguson, A. R. & Bollard, E. G. (1990). "Domestication of the kiwifruit," in *Kiwifruit Science and Management*, I. J. Warrington & G. C. Weston, eds., Ray Richards, Auckland, pp. 165-246.
- Fidler, J. (1968). The metabolism of acetaldehyde by plant tissues. *Journal of Experimental Botany*, 19(1), 41–51.
- Forney, C. F., Kalt, W., & Jordan, M. A. (2000). The composition of strawberry aroma is influenced by cultivar, maturity, and storage. *HortScience*, 35(6), 1022–1025.
- Frank, D., O'Riordan, P., Varelis, P., Zabararas, D., Watkins, P., Ceccato, C., Wijesundera, C., Ferguson, A., Hewett, E., & Gunson, F. (2007). Deconstruction and recreation of 'Hayward' volatile flavour using a trained sensory panel, olfactometry and a kiwifruit model matrix. *Acta Horti*, 753(753), 107–118.
- Friel, E. N., Wang, M., Taylor, A. J., & MacRae, E. A. (2007). In Vitro and in Vivo Release of Aroma Compounds from Yellow-Fleshed Kiwifruit. *Journal of Agricultural and Food Chemistry*, 55(16), 6664–6673. <https://doi.org/10.1021/jf063733x>
- Garcia, C. V., Quek, S.-Y., Stevenson, R. J., & Winz, R. A. (2012). Kiwifruit flavour: A review. *Trends in Food Science & Technology*, 24(2), 82–91. <https://doi.org/10.1016/j.tifs.2011.08.012>
- Günther, C. S., Matich, A. J., Marsh, K. B., & Nicolau, L. (2011). Development of a quantitative method for headspace analysis of methylsulfanyl-volatiles from kiwifruit tissue. *Food Research International*, 44(5), 1331–1338. <https://doi.org/10.1016/j.foodres.2011.01.014>
- Huang, H.-W., & Ferguson, A. (2006). *Actinidia in China*: Natural diversity, phylogeographical evolution, interspecific gene flow and kiwifruit cultivar improvement. *VI International Symposium on Kiwifruit 753* (pp. 31-40).31–40.
- Jordán, M. J., Margaría, C. A., Shaw, P. E., & Goodner, K. L. (2002). Aroma active components in aqueous kiwi fruit essence and kiwi fruit puree by gc-ms and multidimensional gc/gc-o. *Journal of Agricultural and Food Chemistry*, 50(19), 5386–5390. <https://doi.org/10.1021/jf020297f>
- Katsikis, V. (2012). *MATLAB: A Fundamental Tool for Scientific Computing and Engineering Applications -Volume 3*. BoD–Books on Demand. <https://www.mathworks.com/help/stats/index.html>
- Lavilla, T., Recasens, I., & LÁpez, M. (2000). Production of volatile aromatic compounds in Big Top nectarines and Royal Glory peaches during maturity. *Acta Horticulturae*. 553, 233–234.
- Ligor M, Wójcik J, Buszewski B (2004) Application of the solid phase microextraction (spme) and gas chromatography (GC, GC/MS) in food analysis. *Polish J Food Nutr Sci* 13(4), 355–362 <https://www.cabdirect.org/cabdirect/abstract/20073139015>
- Lv, Z., Liu, H., Yang, W., Zhang, Q., Chen, D., Jiao, Z., & Liu, J. (2024). Comprehensive Analysis of Physicochemical Properties and Volatile Compounds in Different Strawberry Wines under Various Pre-Treatments. *Molecules*, 29(9), 2045.
- McDonnell, T., & Pawliszyn, J. (1990). Solid phase microextraction with thermal desorption fused silica optical fibres. *J. Anal. Chem*, 62, 2145–2148.

- McGuire, R. G., & Hallman, G. J. (1995). Coating guavas with cellulose-or carnauba-based emulsions interferes with postharvest ripening. *HortScience*, *30*(2), 294–295.
- Nichols, W. C., & Patterson, M. E. (1987). Ethanol accumulation and poststorage quality of 'Delicious' apples during short-term, low-O₂, CA storage. *HortScience*, *22*, pp. 89-92
- Norman, S., & Houck, L. (1977). The role of volatiles in storage of citrus fruits. *Proc. Int. Soc. Citriculture*, *1*, 238–242.
- Oz, A., Baktemur, G., Kargi, S. P., & Kafkas, E. (2016). Volatile compounds of strawberry varieties. *Chemistry of Natural Compounds*, *52*, 507–509.
- Panighel, A., & Flamini, R. (2014). Applications of solid-phase microextraction and gas chromatography/mass spectrometry (SPME-GC/MS) in the study of grape and wine volatile compounds. *Molecules*, *19*(12), 21291–21309.
- Paterson, V. J., Macrae, E. A., & Young, H. (1991). Relationships between sensory properties and chemical composition of kiwifruit (*Actinidia deliciosa*). *Journal of the Science of Food and Agriculture*, *57*(2), 235–251. <https://doi.org/10.1002/jsfa.2740570208>
- Pelayo, C., Ebeler, S., & Kader, A. (2003). Postharvest life and flavor quality of three strawberry cultivars kept at 5 C in air or air+ 20 kPa CO₂. *Postharvest Biology and Technology*, *27*(2), 171–183.
- Pesis, E. (2005). The role of the anaerobic metabolites, acetaldehyde and ethanol, in fruit ripening, enhancement of fruit quality and fruit deterioration. *Postharvest Biology and Technology*, *37*(1), 1–19. <https://doi.org/10.1016/j.postharvbio.2005.03.001>
- Pesis, E., & Avissar, L. (1990). Effect of postharvest application of acetaldehyde vapour on strawberry decay, taste and certain volatiles. *Journal of the Science of Food and Agriculture*, *52*(3), 377–385. <https://doi.org/10.1002/jsfa.2740520310>
- Petracek, P. D., Joles, D. W., Shirazi, A., & Cameron, A. C. (2002). Modified atmosphere packaging of sweet cherry (*Prunus avium* L., cv. 'Sams') fruit: Metabolic responses to oxygen, carbon dioxide, and temperature. *Postharvest Biology and Technology*, *24*(3), 259–270. [https://doi.org/10.1016/S0925-5214\(01\)00192-2](https://doi.org/10.1016/S0925-5214(01)00192-2)
- Pfannhauser, W. Sensorische und instrumentelle analytische untersuchungen des kiwi-aromas. *Z. Lebensm. Unters. Forsch.* 1988, *187*, 224–228.
- Rassam, M., & Laing, W. (2005). Variation in ascorbic acid and oxalate levels in the fruit of *actinidia chinensis* tissues and genotypes. *Journal of Agricultural and Food Chemistry*, *53*(6), 2322–2326. <https://doi.org/10.1021/jf048197s>
- Reid, L. M., O'Donnell, C. P., & Downey, G. (2004). Potential of spme-gc and chemometrics to detect adulteration of soft fruit purées. *Journal of Agricultural and Food Chemistry*, *52*(3), 421–427. <https://doi.org/10.1021/jf034962b>
- Shiota, H., (1982). Kiwifruit. *Koryo*, *137*, pp. 59-64.
- Sale, P. R. & Lyford, P. B. (1990). Cultural, management and harvesting practices for kiwifruit in New Zealand, in *Kiwifruit. Science and Management*, I. J. Warrington & G. C. Weston, eds., *Ray Richards in association with the New Zealand Society for Horticultural Science*, Auckland, pp. 247-296.
- Starowicz, M., Błaszczak, W., Ciska, E., & Latocha, P. (2022). Characterization of Volatile Organic Compounds in Kiwiberries (*Actinidia arguta*) Exposed to High Hydrostatic Pressure Processing by hs-spme/gc-ms. *Molecules*, *27*(18), 5914. <https://doi.org/10.3390/molecules27185914>
- Statistics Globe. (2022). *Biplot of PCA in Python*. Retrieved from <https://statisticsglobe.com/biplot-pca-python>
- Sun, S. Y., Jiang, W. G., & Zhao, Y. P. (2012). Comparison of aromatic and phenolic compounds in cherry wines with different cherry cultivars by hs-spme-gc-ms and hplc. *International Journal of Food Science & Technology*, *47*(1), 100–106.
- Takeoka, G. R., Guntert, M., Flath, R. A., Wurz, R. E., & Jennings, W. (1986). Volatile constituents of kiwi fruit (*Actinidia chinensis* Planch.). *Journal of Agricultural and Food Chemistry*, *34*(3), 576–578. <https://doi.org/10.1021/jf00069a050>
- Trugo, L. C., & Finglas, P. M. (2003). Encyclopedia of food sciences and nutrition. *L. C. Trugo and PM Finglas, Eds*, 1498–1506.
- Vrhovsek, U., Lotti, C., Masuero, D., Carlin, S., Weingart, G., & Mattivi, F. (2014). Quantitative metabolic profiling of grape, apple and raspberry volatile compounds (vocs) using a gc/ms/ms method. *Journal of Chromatography B*, *966*, 132–139.
- Wan, X. M., Stevenson, R. J., Chen, X. D., & Melton, L. D. (1999). Application of headspace solid-phase microextraction to volatile flavour profile development during storage and ripening of kiwifruit. *Food Res. Int.*, *32* (1999), pp. 175-183
- Wang, M. Y., MacRae, E., Wohlers, M., & Marsh, K. (2011). Changes in volatile production and sensory quality of kiwifruit during fruit maturation in *Actinidia deliciosa* 'Hayward' and *A. chinensis* 'Hort16A.' *Postharvest Biology and Technology*, *59*(1), 16–24. <https://doi.org/10.1016/j.postharvbio.2010.08.010>

- Watkins, C., Silsby, K., & Goffinet, M. (1997). Controlled atmosphere and antioxidant effects on external CO₂ injury of Empire apples. *HortScience*, 32 (1997), pp. 1242-1246
- Young, H., Paterson, V. J., & Burns, D. J. W. (1983). Volatile aroma constituents of kiwifruit. *Journal of the Science of Food and Agriculture*, 34(1), 81–85. <https://doi.org/10.1002/jsfa.2740340112>
- Zhang, C.-Y., Zhang, Q., Zhong, C.-H., & Guo, M.-Q. (2016). Analysis of volatile compounds responsible for kiwifruit aroma by desiccated headspace gas chromatography–mass spectrometry. *Journal of Chromatography A*, 1440, 255–259. <https://doi.org/10.1016/j.chroma.2016.02.056>
- Zhao, N., Zhang, Y., Liu, D., Zhang, J., Qi, Y., Xu, J., Wei, X., & Fan, M. (2020). Free and bound volatile compounds in ‘Hayward’ and ‘Hort16A’ kiwifruit and their wines. *European Food Research and Technology*, 246(5), 875–890. <https://doi.org/10.1007/s00217-020-03452-9>.