International Food Research Journal 32(4): 945 - 957 (August 2025)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effects of storage with and without stem on volatile substances of string-harvest tomato

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Article history

Received:
24 March 2024
Received in revised form:
22 September 2025
Accepted:
28 September 2025

Keywords

string-harvest tomato, volatile substances, storage, metabolomics

Abstract

String-harvest tomatoes stored with the stem intact are considered to have a longer shelf life than tomatoes picked off the vine, and stored individually. However, the specific preservation mechanism and the effect of the stem on the formation of flavour substances during storage remain unclear. In the present work, metabolomics was used to determine the volatile compounds of tomatoes harvested in bunches with (LC1) and without (LC2) stems during refrigerated storage. After six days of storage, the composition and concentration of volatile compounds in the LC1 and LC2 groups were significantly different from those in the control group (frozen and preserved in liquid nitrogen before refrigerated storage). Comparing to CK group, the contents of methyl dodecanoate, ethyl dodecanoate, phellandrene, limonene, and dodecanoic acid, which are related to floral, fruity, cool mint, lemon, and sweet aroma, respectively, significantly decreased, whereas substances with foul or pungent odours, such as isobutyronitrile and phenol, significantly increased in the LC1 group. In the LC2 group, ester aromatics—such as dodecanoic acid methyl ester and dodecanoic acid ethyl ester—significantly decreased, along with benzenoids including phenol-2-nitro and phenol-2-methoxy, compared to the CK group. The concentrations of alkane volatiles were higher in LC2 than in the tomatoes with stems (LC1). These results suggested that regardless of whether the tomatoes had stems or not, the ester volatiles decreased during storage, whereas the alkane volatiles in tomatoes without stems increased compared to those with stems.

DOI
https://doi.org/10.47836/ifrj.32.4.04

Introduction

Tomato is an important and popular vegetable consumed worldwide with a long history and numerous varieties. The picking time, storage conditions, and storage time of tomatoes all affect their edible quality (Natalini *et al*., 2021; Yan *et al*., 2021; Ciptaningtyas *et al*., 2022). Cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) is one of the four priority fruits supported by the Food and Agriculture Organization of the United Nations, along with apples, grapes, and bananas. In particular, string-harvest cherry tomatoes are more popular among consumers owing to their enhanced appearance and longer shelf life. Previous studies have shown that the shelf life of string-harvested tomatoes with stems is longer than that of single-harvested tomatoes (Tsouvaltzis *et al*., 2023), indicating that string-harvesting plays a role in tomato preservation and storage. Wang *et al*. (2017) suggested that string-harvesting or harvesting with stems (and leaves) can delay the senescence of fruits. They investigated the effects of string harvest on ethylene production and storage quality in post-harvest tomatoes, and found that the string-harvest treatment inhibited the post-harvest accumulation of soluble sugars and the degradation of titratable acid to a certain extent. Moreover, the string-harvest treatment inhibited ethylene production in the fruit; increased carotenoid, lycopene, and ascorbic acid levels; and delayed post-harvest changes of sugar and acid contents, ultimately extending tomato shelf life, and improving the commodity quality. However, the effects of string-harvest treatment on the volatile components of tomatoes that influence flavour properties during post-harvest storage have not been reported to date.

The typical quality measurement indicators of tomatoes include soluble solid content, total sugar content, organic acid content, sugar acid ratio,

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vitamin C content, amino acid content and composition, and volatile flavour compounds (Wang *et al*., 2022; Erika *et al*., 2022). These indicators have been widely used to evaluate the quality of tomatoes according to variety, storage periods, and preservation techniques. For example, Liu *et al*. (2023a) demonstrated that a hydroxyethyl cellulose and 20% sulphated rice bran polysaccharide preservative coating significantly reduced cherry tomato quality deterioration and weight loss, delayed firmness loss, and maintained high levels of titratable acid, ascorbic acid, total phenols, carotenoids, and volatile substances during cold storage. The development of technologies such as metabolomics has promoted research on the quality and flavour of tomatoes in storage. These studies have mainly focused on the effects of tomato varieties, storage environment, and additives on tomato flavour and the underlying mechanism (Cai *et al*., 2024; Shu *et al*., 2025; Henschel *et al*., 2025). Bai *et al*. (2023) analysed the post-harvest ripening and senescence of tomatoes under low temperature using transcriptomics and metabolomics approaches. They found that the contents of many metabolites in tomatoes were greatly affected by storage temperature, including organic acids, sugars, and phenols.

Volatile components constitute a crucial aspect of tomato flavour quality; accordingly, the variations in volatile substances during the post-harvest storage of tomatoes have attracted significant research attention. Tao *et al*. (2024) found that low-temperature storage reduced volatile compound synthesis. Specifically, the levels of benzyl alcohol, hexanal, 2-hexanol, 4-hydroxy-benzeneethanol, hotrienol, (Z)-3,7-dimethyl-2,6-octadienal, (Z)-3-hexenal, heptanal, 2-ethyl-1-hexanol, 2-isobutylthiazole, and (E)-2-methyl-2-butenal, which all contribute to tomato aroma, were higher in the group stored at 20°C than in those stored at 0°C for eight days. Liu *et al*. (2023b) demonstrated that the application of 24-epibrassinolide improved the quality characteristics of tomatoes during post-harvest storage according to a modelling analysis of the volatile compound regulation network.

The metabolism of sensory, gustatory, and aromatic substances in tomatoes during storage is a complex network system. Although low-temperature storage is demonstrated to be beneficial for tomato preservation, it is not conducive to aroma formation (Tao *et al*., 2024). To examine the impact of harvesting tomatoes with stems on aroma formation during storage, in the present work, we examined the volatile compounds produced during storage of tomatoes with and without fruit stems, along with the possible metabolic pathways involved in these differences. The obtained and presented results could provide a new perspective for improving tomato storage methods with enhanced quality and flavour.

Materials and methods

Chemicals and reagents

The *n*-alkanes(C7-C30) standards, purchased from Sigma-Aldrich, were used for retention index (RI) calibration.

Sample preparation

String-harvest tomatoes (full ripe) were purchased from Sam's supermarket in Hangzhou. The product information for a 1-kg package stated that the origin was Inner Mongolia, the tomatoes were planted and grown in a greenhouse, and it is recommended to store the tomatoes in the refrigerator. For this experiment, a string of tomatoes was randomly removed from the package, and the tomatoes on one side of the string were kept on the branch (LC1), while the tomatoes on the other side were picked off the stems and preserved together (LC2). Three tomatoes were randomly picked from the same bunch, and directly frozen in liquid nitrogen to serve as the control group (CK). Therefore, the three groups of tomatoes were derived from the same branch to ensure the comparability of the experimental results (Figure 1).

The tomatoes were crushed in liquid nitrogen and a 2 g sample was placed in a 20-mL Agilent headspace bottle, set on the sampling tray, and subjected to gas chromatography coupled with time-of-flight mass spectrometry (GC-TOF-MS) (Figure 1).

Solid-phase microextraction conditions

GC-TOF-MS analysis was performed using an Agilent 7890B gas chromatograph coupled with a TOF-MS system (Pegasus BT 4D, Leco). DB-WAX served as the first-dimension column, and DB-17SilMS was used as the second-dimension capillary column for separation. Helium was used as the carrier gas at a constant flow rate of 1.0 mL/min. The extraction conditions were as follows: extraction head, DVB/CAR/PDMS 50/30 μm, 2 cm; extraction

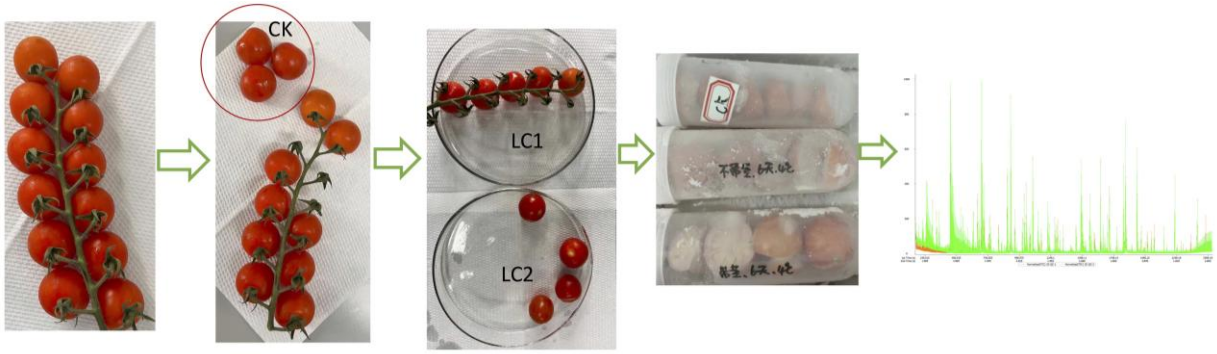

Figure 1. Schematic diagram of experimental design. Harvested tomatoes were randomly divided into three groups: control group (CK), group with stem (LC1), and group without stem (LC2). The CK group was frozen with liquid nitrogen, and stored at -80°C. The LC1 and LC2 groups were stored at -4°C for six days, followed by liquid nitrogen quick freezing, and stored at -80°C. All three groups of tomatoes then underwent metabolomics analysis of volatile substances.

temperature, 80°C; incubation time, 10 min; and extraction time, 30 min.

For GC-TOF-MS, the injection temperature was set to 250°C, the transfer interface temperature was 270°C, and the source temperature was 220°C. The initial temperature was kept at 40°C for 3 min, raised to 70°C at a rate of 3°C/min, then raised to 245°C at a rate of 5°C/min, and held at 245°C for 8 min. The energy was 70 eV in electron impact mode. The MS data were acquired in full-scan mode within an *m/z* range of 33 - 550 at a rate of 100 spectra per second.

To monitor the stability and repeatability of instrument analysis, quality control (QC) samples were prepared by pooling part of each sample, and these QC samples were analysed together with the test samples. The RI and fragment ion spectrum of metabolites in the NIST database were matched, and the identification results were manually checked. The reliability of metabolite identification was above level 2 (Blazenovic *et al*., 2018).

Data processing

The raw data were processed using ChromaTOF software (v4.71, Leco) for automated baseline denoising and smoothing, peak picking, deconvolution, and peak alignment. Compound identification was performed by matching the mass spectrum and RI with corresponding values in the NIST database.

Data quality evaluation

Repeatability of the results and reliability of data quality were assessed through the total ion chromatogram (TIC), principal component analysis (PCA), QC samples correlation, Hotelling's T2 test, multivariate control chart (MCC), and relative standard deviation (RSD).

Statistical analysis

After sum-normalisation, the processed data were analysed by the R package ropls, involving multivariate data analysis, including Pareto-scaled PCA and orthogonal partial least-squares discriminant analysis (OPLS-DA). Seven-fold cross-validation and response permutation testing were used to evaluate the robustness of the model. The variable importance in the projection (VIP) value of each variable in the OPLS-DA model was calculated to indicate its contribution to the classification. Student's *t*-test was applied to determine the significance of differences between two groups of independent samples. VIP > 1 and $p < 0.05$ were set as the criteria to screen significantly changed metabolites. Pearson's correlation analysis was performed to determine the correlation between two variables.

Results

Morphological changes of tomatoes during refrigeration

As shown in Figure 2, during the fourth to sixth days of 4°C refrigeration, tomatoes without stems showed a substantial decrease in hardness compared to that of the tomatoes stored with stems; however, there were no signs of rotting. Considering that most households will not store tomatoes for over seven days, we evaluated the tomatoes after six days of refrigeration.

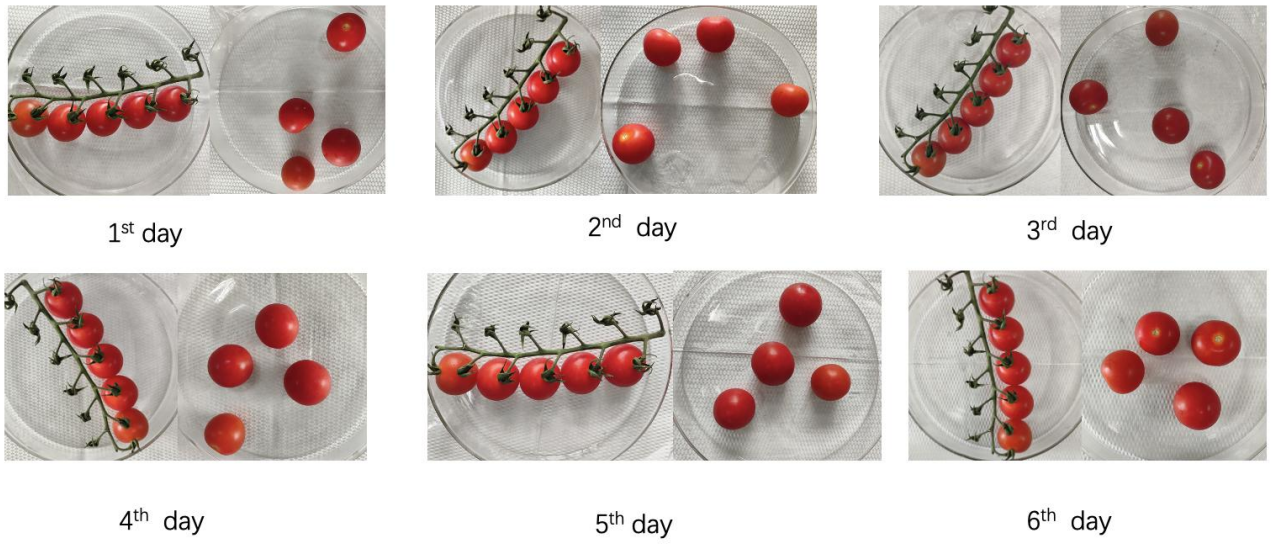

Figure 2. Morphological changes of each group of tomatoes during six-day refrigeration.

Data quality evaluation

The total ion chromatograms (TIC) of QC samples were overlaid for comparison, as shown in Figure 3A. The results indicated that the response intensity and retention time of the chromatographic peaks were largely consistent, suggesting minimal variability introduced by instrumental error throughout the experimental process. Peaks extracted from all experimental samples and QC samples were subjected to principal component analysis (PCA), as presented in Figure 3B. The results demonstrated that the QC samples clustered closely together, indicating high reproducibility of the experiments. The relative standard deviation (RSD) of ion peak abundance in QC samples reflects instrumental stability, with lower RSD values indicating better data quality. In this experiment, more than 80% of the peaks in QC samples had an RSD ≤ 30%, as shown in Figure 3C, demonstrating good stability of the instrumental analysis system, and confirming that the data were reliable for further processing. The multivariate control chart (MCC) is a quality management tool based on a multivariate statistical model constructed from ion peaks detected in QC samples. It is used to monitor and evaluate the stability of instrument performance. Each point in the MCC represents a QC sample, and the X-axis corresponds to the sequence of sample injections. Fluctuations in the points reflect variations in instrument status. The acceptable range is typically within ± 3 standard deviations. The MCC for the QC samples in this project is shown in Figure 3D. The results indicated that all QC samples fluctuated within ± 3 standard deviations, suggesting that instrument variability was under control, and the data were suitable for subsequent analysis. Pearson's correlation analysis was performed on the QC samples, as illustrated in Figure 3E. A correlation coefficient greater than 0.9 is generally considered indicative of a strong correlation. The results showed that all correlation coefficients between QC samples were above 0.9, confirming good experimental reproducibility. Hotelling's T2 test, which examines samples through multivariate modelling with defined 95 or 99% confidence intervals, was applied for outlier detection. The results of the Hotelling's T2 test are shown in Figure 3F. All QC samples fell within the 99% confidence interval, demonstrating high reproducibility.

In summary, the results of TIC, PCA, QC samples correlation, Hotelling's T2 test, MCC, and RSD show that the experimental data were reliable (Figure 3).

Classification of tomato volatile substances

All metabolites identified in this experiment were categorised and statistically analysed based on their chemical classification information, with the proportional distribution of metabolites across various classes shown in Figure 4A. Alcohols were the dominant volatile substances, accounting for 17.014% of the identified metabolites, followed by benzenoids (15.972%), alkanes (15.451%), aldehydes (12.674%), and ketones (8.854%). Principal component analysis (Figure 3B) revealed clear

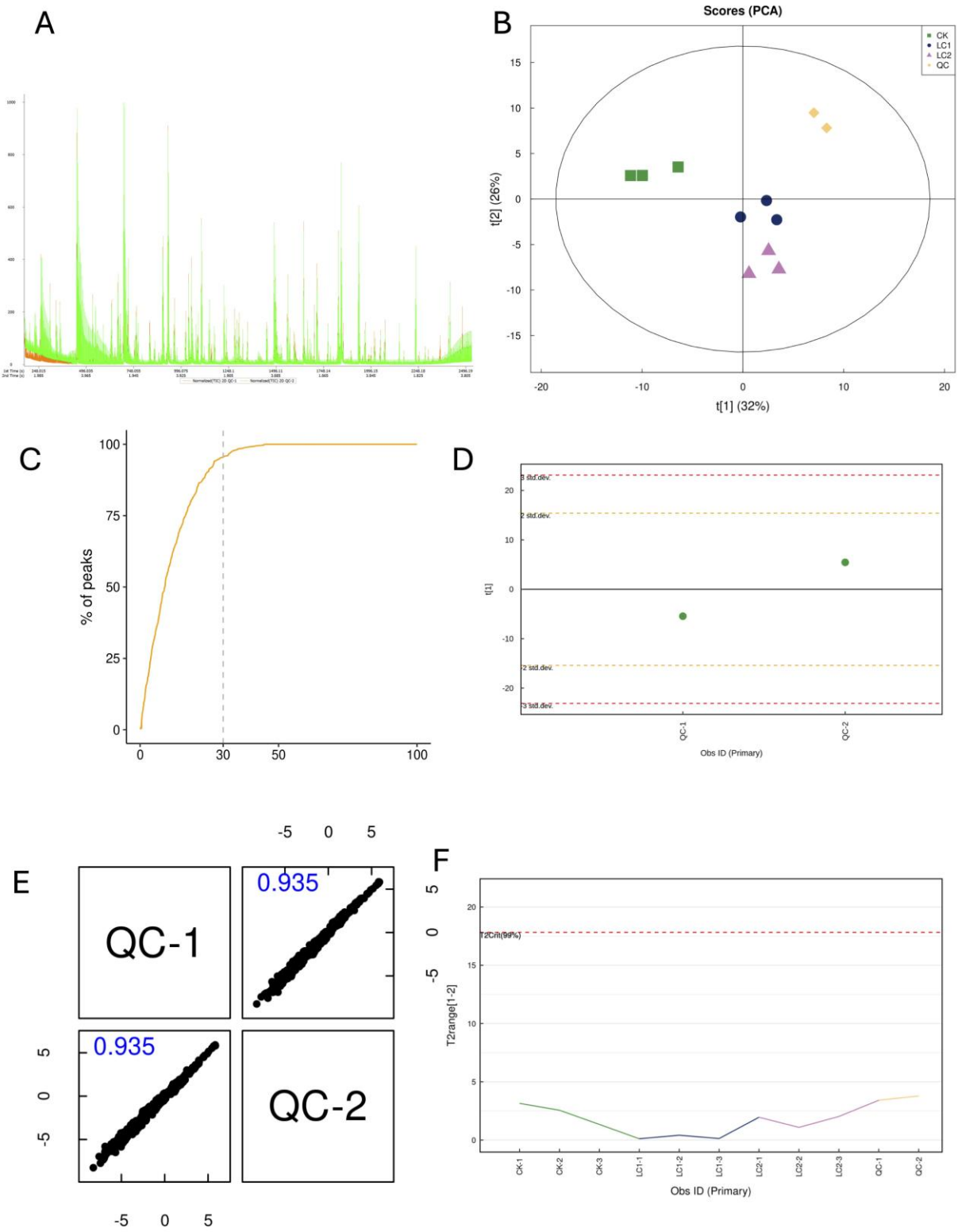

Figure 3. Data quality evaluation. **(A)**: TIC, **(B)**: PCA, **(C)**: RSD, **(D)**: MCC, **(E)**: QC samples correlation; and **(F)**: Hotelling's T2 test.

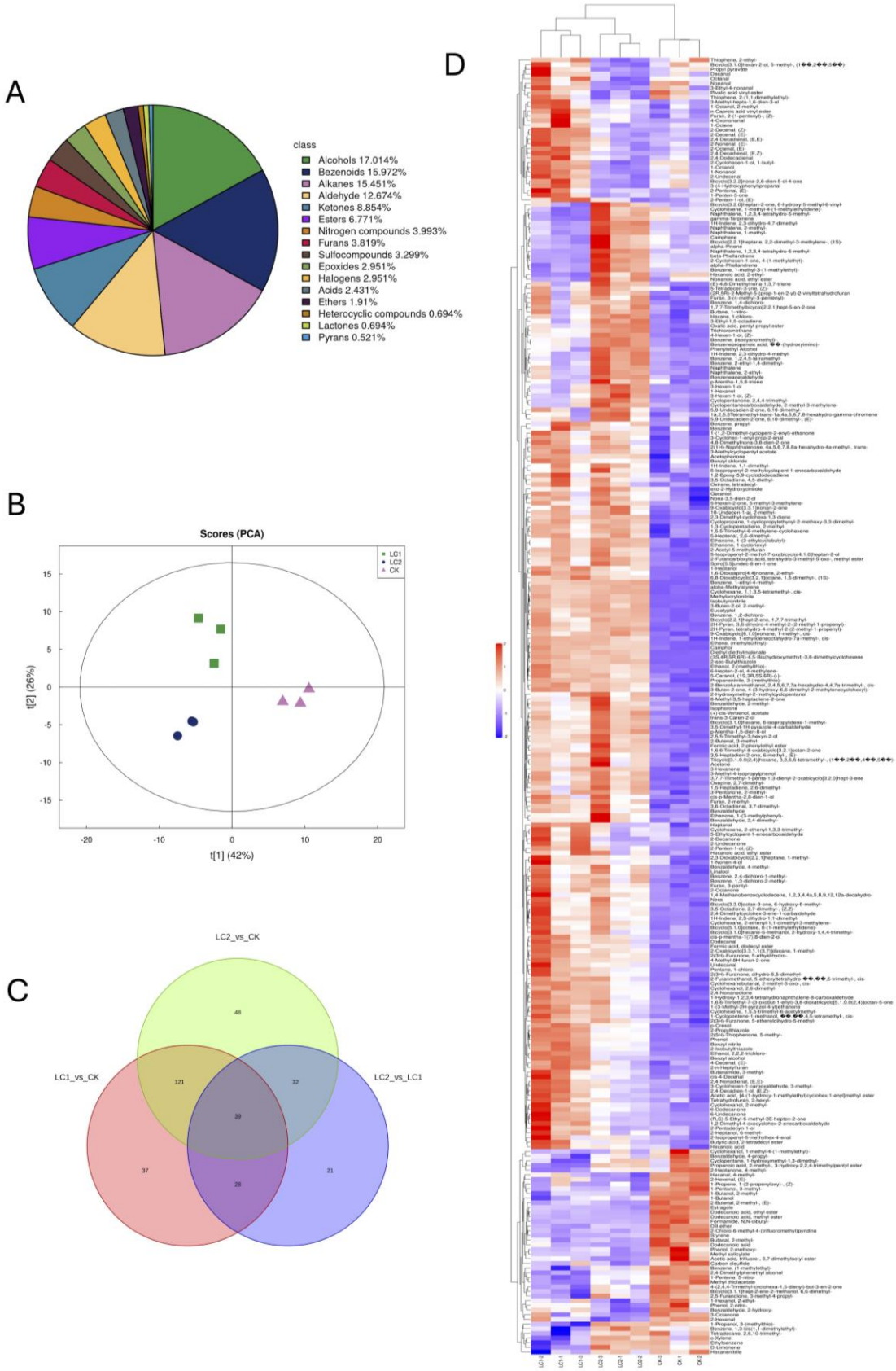

Figure 4. Composition and proportion of volatile substances.

separation among the three groups in terms of volatile substance composition, demonstrating the reliability of the method. The overlap of significantly differential metabolites screened across different groups is illustrated in Figure 4C. The hierarchical clustering analysis results of the significantly differential metabolites (variable importance in projection (VIP) > 1 and *p*-value < 0.05) are presented in Figure 4D. Metabolites clustered within the same branch exhibit similar expression patterns, and may collectively participate in the same metabolic process.

Differences of volatile substances among three treatment groups

Differential metabolites were screened using the criteria of OPLS-DA with VIP > 1 and *p*-value < 0.05. As shown in Figure 5, compounds were further selected based on a fold change (FC) threshold of either > 1.5 or < 0.67, with a *p*-value < 0.05. The metabolites presented in Tables 1 - 3 were identified using OPLS-DA with VIP > 1, FC > 1.5 or < 0.67, and *p*-value < 0.05. Compared to the CK, tomatoes stored with stems for six days had 225 different metabolites. Fifteen major classes of significantly different compounds are listed in Table 1, ranging from acids and alcohols to sulphurous compounds. Compared to CK, the LC1 group showed a significant decrease in ester aroma compounds, including dodecanoic acid methyl ester, dill ether, and dodecanoic acid ethyl ester. The overall changes in metabolite profiles are visualised in the volcano plot (Figure 5A). A total of 240 different metabolites were identified between tomatoes without stems (LC2) refrigerated for six days, and the CK (Figure 5B and Table 2). Among the top ten most significantly altered volatile substances in LC2, both increases and decreases were observed in sulphides and nitrogenous compounds. Ester aromatics—such as dodecanoic acid methyl ester and dodecanoic acid ethyl ester—significantly decreased, along with benzenoids including phenol-2-nitro and phenol-2-methoxy. A total of 120 different metabolites were identified between tomatoes stored for six days with and without stems (Table 3 and Figure 5C). Relative to LC1, LC2 exhibited a notable increase in alkane volatile compounds, such as α-phellandrene, β-phellandrene, D-limonene, 4-(1-methylethyl)-2-cyclohexen-1-one, α-pinene, γ-terpinene, and 3-hexen-1-ol.

Discussion

Overall, harvesting tomatoes with stems was found to be conducive to maintaining the freshness of the fruit during refrigerator storage, which is consistent with a previous study (Wang *et al*., 2017). However, few studies have examined the mechanism by which the tomato stem and branch promote quality preservation during storage. Wang *et al*. (2017) considered that string-harvesting avoided the formation of wounds in tomatoes, and prevented some disadvantages, such as bacterial infection. Their results showed that harvesting tomatoes together on the branch could prolong the fruit shelf life, and improve the commodity quality by inhibiting the synthesis of ethylene; increasing the levels of carotenoids, lycopene, and ascorbic acid; and delaying the ripening process of nutrients such as sugars and acids. However, they did not examine the impact of the stem on volatile substances.

Approximately 400 types of volatile substances have been identified in tomatoes to date, which are mainly divided into aldehydes, alcohols, ketones, esters, acids, phenols, terpenoids, hydrocarbons, and sulphur / nitrogen / oxygen polyheterocyclic compounds (Mathieu *et al*., 2009). Different kinds of volatile substances have substantial effects on the overall odour signature. Aldehydes are the main volatiles of green leaves, characterised by a scent of green grass, thereby increasing the overall freshness perception of tomatoes (Wakai *et al*., 2019; Engelberth and Engelberth, 2020; Su *et al*., 2020). Alcohols are responsible for the sweetness flavour, playing an important role in increasing the quality of tomato (Tandon *et al*., 2000). Ketones contribute to the scents of flowers, berries, and sweetness, which are favoured by many consumers (Aubert and Chalot, 2018). Phenols have a pungent odour that makes people feel unpleasant (Inga *et al*., 2019; Liu *et al*., 2019). A small ester content of tomatoes results in low consumer preference. There are 16 types of volatile substances in fresh tomatoes that play a crucial role in the flavour, including (Z)-3-hexenal, β-ionone, hexanal, β-damaketone, 1-penten-3-one, 2,3-methylbutyraldehyde, (E)-2-hexenal, 2-isobutylthiazole, 1-nitro-2-ethylbenzene, (E)-2-heptenal, phenylacetaldehyde, 6-methyl-5-hepten-2-one, (Z)-3-hexenol, 2-phenylethanol, 3-methylbutanol, and methyl salicylate (Yilmaz *et al*.,

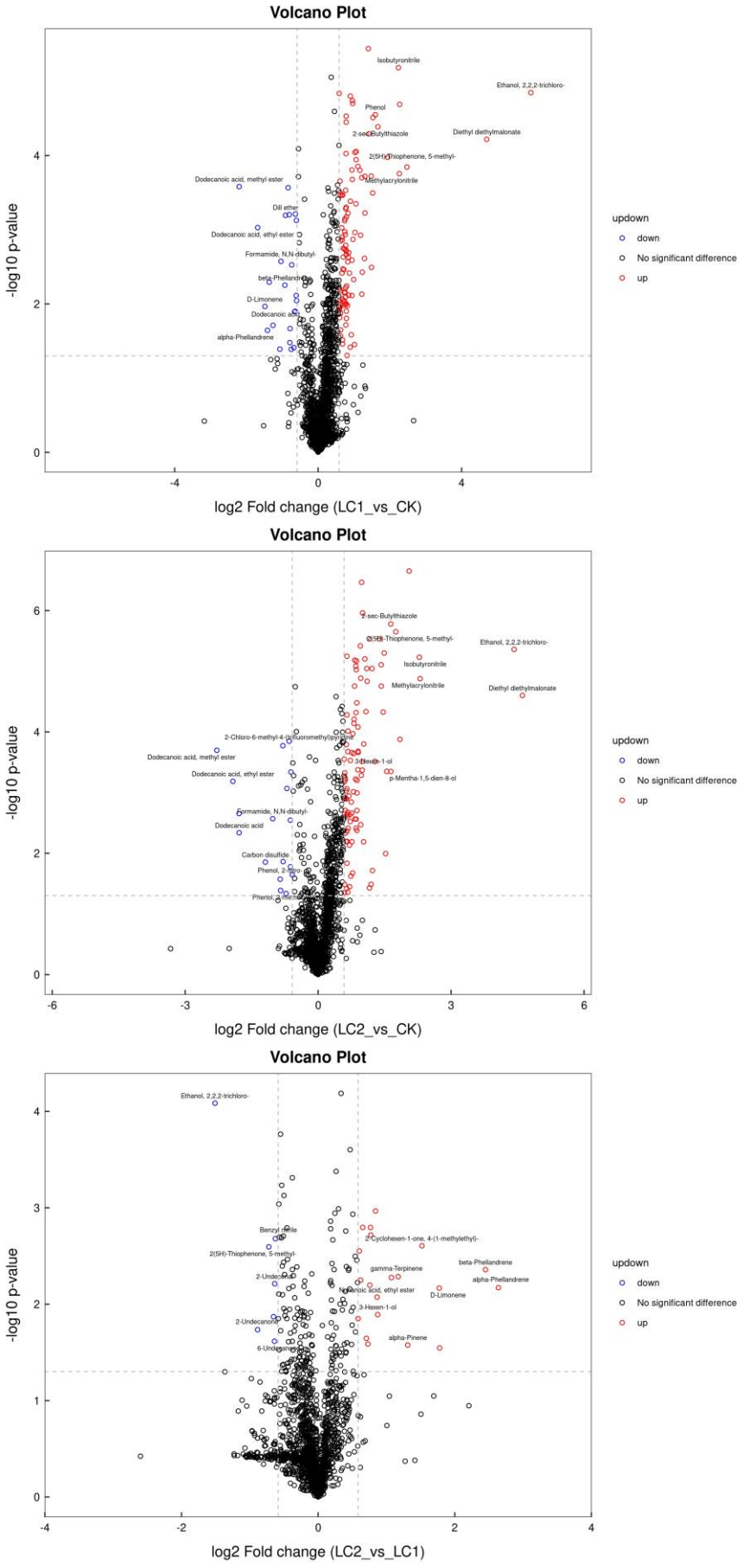

Figure 5. Different metabolites shown in volcano plots (FC > 1.5 or FC < 0.67; *p*-value < 0.05; *n* = 3).

Table 1. Differences in volatile substances between LC1 and CK groups (OPLS-DA VIP > 1; FC > 1.5 or FC < 0.67; *p*-value < 0.05; *n* = 3).

Type of compound with significant difference	**Metabolite upregulated in LC1 group compared to CK group**	
Acid	**Compound**	**Class**
Alcohol	Ethanol, 2,2,2-trichloro-	Halogens
Aldehyde	Diethyl diethylmalonate	Esters
Alkane	2(5H)-Thiophenone, 5-methyl-	Sulfocompounds
Benzenoid	Methylacrylonitrile	Nitrogen compounds
Epoxide	Isobutyronitrile	Nitrogen compounds
Ester	2-sec-Butylthiazole	Sulfocompounds
Ether	Phenol	Benzenoids
Furan	**Metabolite downregulated in LC1 group compared to CK group**	
Halogen	**Compound**	**Class**
Heterocyclic compound	Dodecanoic acid, methyl ester	Ester
Ketone	Dill ether	Ether
Nitrogenous compound	Dodecanoic acid, ethyl ester	Ester
Pyran	Formamide, N,N-dibutyl-	Nitrogenous compound
Sulphurous compound	beta-Phellandrene	Alkane
/	D-Limonene	Alkane
/	Dodecanoic acid	Acid
/	alpha-Phellandrene	Alkane

Table 2. Differences in volatile substances between LC2 and CK groups (OPLS-DA VIP > 1; FC > 1.5 or FC < 0.67; *p*-value < 0.05; *n* = 3).

Type of compound with significant difference	**Metabolite upregulated in LC2 group compared to CK group**	
Acid	**Compound**	**Class**
Alcohol	Diethyl diethylmalonate	Ester
Aldehyde	Ethanol, 2,2,2-trichloro-	Halogen
Alkane	Methylacrylonitrile	Nitrogenous compound
Benzenoid	Isobutyronitrile	Nitrogenous compound
Epoxide	2(5H)-Thiophenone, 5-methyl-	Sulphurous compound
Ester	p-Mentha-1,5-dien-8-ol	Alcohol
Ether	2-sec-Butylthiazole	Sulphurous compound
Furan	3-Hexen-1-ol	Alcohol
Halogen	**Metabolite downregulated in LC2 group compared to CK group**	
Heterocyclic compound	**Compound**	**Class**
Ketone	Dodecanoic acid, methyl ester	Ester
Lactone	Dodecanoic acid, ethyl ester	Ester
Nitrogenous compound	Dodecanoic acid	Acid
Pyran	Carbon disulphide	Sulphurous compound
Sulphurous compound	Formamide, N,N-dibutyl-	Nitrogenous compound
/	Phenol, 2-nitro-	Benzenoid
/	Phenol, 2-methoxy-	Benzenoid
/	2-Chloro-6-methyl-4-(trifluoromethyl)pyridine	Nitrogenous compounds

Table 3. Differences in volatile substances between LC2 and LC1 groups (OPLS-DA VIP > 1; FC > 1.5 or FC < 0.67; *p*-value < 0.05, *n* = 3).

Type of compound with significant difference	**Metabolite upregulated in LC2 group compared to LC1 group**	
Acid	**Compound**	**Class**
Alcohol	alpha-Phellandrene	Alkane
Aldehyde	beta-Phellandrene	Alkane
Alkane	D-Limonene	Alkane
Benzenoid	2-Cyclohexen-1-one, 4-(1-methylethyl)-	Ketone
Epoxide	alpha-Pinene	Alkane
Ester	gamma-Terpinene	Alkane
Ether	3-Hexen-1-ol	Alkane
Furan	Nonanoic acid, ethyl ester	Ester
Halogen	**Metabolite downregulated in LC2 group compared to LC1 group**	
Ketone	**Compound**	**Class**
Nitrogenous compound	Ethanol, 2,2,2-trichloro-	Halogen
Sulphurous compound	2-Undecanone	Ketone
/	2(5H)-Thiophenone, 5-methyl-	Sulphurous compound
/	6-Undecanone	Ketone
/	2-Undecenal	Aldehyde
/	Benzyl nitrile	Nitrogenous compound
/	(R,S)-5-Ethyl-6-methyl-3E-hepten-2-one	Alcohol

2006). Flavours that are favoured by consumers are typically the soluble solids, reducing sugars, citric acid, geranyl acetone, 6-methyl-5-heptan-2-one, β-ionone, β-cyclocitral, geranial, linalool, 1-penten-3-one, (Z)-3-hexene-1-ol, (E)-3-hexene-1-ol, hexanal, heptanal, (E)-2-heptenal, 2-octenal, benzaldehyde, 2-phenethyl alcohol, phenylacetaldehyde, phenylacetaldehyde, and 2-isobutylthiazole (Lee *et al*., 2018; Zhao *et al*., 2019). Substances negatively related to flavour include malic acid, salicaldehyde, butyl acetate, hexyl acetate, amyl acetate, isobutyl acetate, methyl salicylate, 3-methyl-1-butanol, and guaiacol (Marcinkiewicz, 2017; Klee and Tieman, 2018).

In this experiment, compared to CK, the contents of methyl dodecanoate, ethyl dodecanoate, phellandrene, limonene, and dodecanoic acid significantly decreased in LC1, corresponding to floral, fruity, cool mint, lemon, and sweet aromas, respectively. Moreover, compounds such as D-limonene and alpha-phellandrene are important antibacterial volatiles (Wei *et al*., 2024; Munawar *et al*., 2025), which were found to decrease during refrigerated storage of tomatoes with stems. Therefore, the changes in volatile compounds during tomato storage may influence the overall aroma and antibacterial properties.

However, substances with foul and pungent odours, such as isobutyronile and phenol, significantly increased in tomatoes stored on stems compared to the control. These compounds belong to nitrogenous compounds, sulphurous compounds, and benzenoids, which have been reported as components that are detrimental to tomato aroma (Du *et al*., 2015; Liscombe *et al*., 2022; Guo *et al*., 2023).

After six days of refrigeration, there was a major decrease in the contents of methyl dodecanoate, ethyl dodecanoate, and dodecanoic acid in tomatoes without stems compared to the control, which was similar to the changes found for the tomatoes stored with stems. However, in contrast to the changes in LC1, the phenol pungent flavour compounds significantly decreased in tomatoes stored without stems. Compared with those of CK, the contents of phellandrene and limonene did not significantly decrease in LC2.

Comparing the two experimental groups showed that LC2 contained far more flavour substances related to fruit-ripening aromas, such as phellandrene, α-pinene, and limonene, than LC1. In addition, 3-hexene-1-ol, which is typically preferred by consumers (Guo *et al*., 2023), was more abundant in LC2 than in LC1.

Previous reports have shown that low-temperature storage is detrimental to the formation of tomato aroma, which may be related to the inhibition of ethylene synthesis. Wang *et al*. (2017) found that tomatoes harvested with stems and branches showed a significant decrease in ethylene synthesis, and a significant increase in carotenoid and lycopene contents during storage. The formation pathways of tomato aroma include the biosynthetic pathways of fatty acids, amino acids, and carotenoids as precursors. Consistent with previous research findings, the present work confirmed that refrigeration (low temperature) would be disadvantageous to tomato aroma (Tao *et al*., 2024; Guan *et al*., 2025), possibly by inhibiting ethylene synthesis, and affecting fatty acid, carotenoid, and amino acid metabolism pathways (Wang *et al*., 2016). Notably, the content of 3-hexene-1-ol in LC2 was significantly higher than that in LC1, indicating that storage of tomato with the stem inhibited the biosynthesis pathway of volatile compounds using fatty acids as precursors.

Some limitations of the present work should be acknowledged for cautious interpretation of the results. Due to the wide variety of volatile substances, the ultimate flavour and sensory profile can be quite different based on the specific content and proportion. As noted by Liscombe *et al*. (2022), although nitrogenous volatiles tend to have pungent, medicinal odours at higher concentrations, they can impart desirable flavour qualities at lower concentrations as part of volatile blends. However, it remains a widespread challenge in flavour research to accurately interpret aroma profiles due to the current lack of analytical techniques capable of comprehensively evaluating the synergistic effects of compound ratios. In the present work, we mainly focused on the changes of the first eight to ten types of substances identified. Without considering the threshold and proportion of flavour compounds, the interpretation of the broader effects may be limited. Therefore, the various volatile substances in the tomatoes stored under different conditions, and their impact on quality and consumer preference should be further explored in the future.

In summary, regardless of whether the tomatoes had stems or not, the ester volatiles decreased during storage, whereas the alkane volatiles in tomatoes without stems increased compared to those with stems.

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