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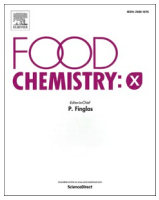

# Effects of different sterilisation methods on the quality and flavor of non from concentrate (NFC) *Actinidia arguta* juice

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ABSTRACT

Sterilisation is one of the most important means to extend the shelf life of fruit juices. In this paper, the effects of four sterilisation methods, ultraviolet (UV), ultrasonic (US), ultrahigh pressure (UHP) and low temperature long time (LTLT), on *Actinidia arguta* juice were investigated. The results showed that all four methods were able to reduce the microbial population below the safety limit, had no significant effect on pH, but increased the total soluble solids content and reduced the total acid content. UV, US and UHP were more effective in retaining nutrients, while LTLT significantly reduced chlorophyll, total sugars, total flavonoids, total phenols and ascorbic acid content ($p < 0.05$). UHP improved the colour better, while UV better preserved the original flavor. This study will provide an alternative strategy for thermal pasteurization of traditional NFC fruit juices.

## 1. Introduction

*Actinidia arguta (A. arguta)*, also known as cold-tolerant kiwifruit, is a perennial, dioecious vine in the kiwifruit family (Pinto et al., 2020). It is native to China, Korea, eastern Russia and Japan, and has since been introduced to New Zealand, the United States and elsewhere (Lai et al., 2015). Compared to traditional kiwifruit, the hairless skin of the *A. arguta* allows it to be eaten straight away, making it a popular choice among consumers. *A. arguta* fruit is rich in vitamins, minerals, polyphenols, flavonoids, pectin, polysaccharides and other biologically active components (Lin et al., 2022; Liu et al., 2024). These characteristics have also made *A. arguta* quickly become the third most widely planted member of the kiwifruit family in the world in recent years (Lu et al., 2022). Fruit juice is a processed fruit product that most truly reflects the original colour and flavor of fresh fruit. The current state of the art in juice preservation technology reflects the dual need for extended shelf life and nutrient retention. From the traditional heating method to modern high-pressure processing, membrane filtration and other new technologies, the field of fruit juice preservation is evolving to meet market demand and consumers' pursuit of healthy, natural drinks (Prestes et al., 2023). The main preservation problems facing fruit juices are nutrient loss, oxidation problems and microbial contamination. Starting from the production and processing of fruit juice is the key to solve the above problems.

In the production and processing of fruit juice, mainly including raw material pretreatment, juicing, canning and sterilisation of four key steps. Sterilisation is the basic and key link to ensure the normal flow of products, the effect of sterilisation directly affects the product status and shelf life of fruit juice (Maria de Fátima et al., 2020). Sterilisation techniques for fruit juices are divided into thermal and non-thermal sterilisation. The basic principle of thermal sterilisation is to inactivate enzymes and micro-organisms through high temperatures and to reduce heat-sensitive substances so as to achieve the purpose of prolonging the shelf-life of foodstuffs (Zhao et al., 2023). However, its disadvantages are also obvious, high temperature is easy to lead to the loss of food nutrients and sensory deterioration. Common thermal sterilisation methods include low temperature long time sterilisation (LTLT) and high temperature transient sterilisation (HTT). With the development of science and technology and the improvement of consumers' requirements, non-thermal sterilisation technology has widely entered the public's view in recent years. Common non-thermal sterilisation techniques include ultraviolet (UV), ultrasound (US), ultrahigh pressure (UHP) and irradiation (IR). Different methods of sterilisation affect the physicochemical properties, nutritional quality and organoleptic properties of fruit juices to different degrees (Lv et al., 2024). NFC juice as a kind of original juice, for the nutrients and shelf life of the requirements will be more stringent. From the current research, most of the studies on the sterilisation technology of NFC juices compare thermal and non-thermal sterilisation. For example, Yang et al. (Yang et al., 2019) explored the effects of hot pasteurization and UV treatment on

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microbiological and quality parameters of NFC apple juice and found that UV treatment could better maintain the freshness characteristics of the product. Tarek et al. (Abedelmaksoud et al., 2019) also experimented with NFC apple juice, comparing heat sterilisation and ohmic sonication (OS), and showed that the loss of active ingredients in the juice was lower under OS treatment. UHP has dominated the non-thermal production of fruit juices as a promising sterilisation technology. UHP treatment allows better retention of the sugar-acid content, functional components and antioxidant activity of pear juice, reduces browning and improves the stability of the juice (Gan et al., 2023). The chlorophyll content of cucumber juice was significantly reduced when the temperature was increased to 85 °C, whereas there was no significant effect on chlorophyll when cucumber juice was treated at 500 MPa/2 min pressure (Zhao et al., 2013).

However, there are no studies on NFC *A. arguta* juice on the market and no reports on the comparison of sterilisation methods for NFC juices. Therefore, this study investigated the effects of four sterilisation methods, namely, UV, US, UHP and LTLT, on the microorganisms, pHysicochemical indexes, bioactive components, colour and flavor of *A. arguta* juice. It provides theoretical basis and application reference for the industrialization of *A. arguta* and NFC juices.

## 2. Materials and methods

### 2.1. Materials and chemicals

*A. arguta* is provided by the College of Landscape Architecture, Changchun University. Plate counting agar (PCA), purplish red bile agar (VRBA), and rose Bengal chloramphenicol agar (RBCA) were purchased from Auboxin Bio-technology (Beijing, China). Sulfuric acid, sodium hydroxide, sodium carbonate, ethanol, aluminum nitrate and sodium nitrite were purchased from Beijing Chemical Industry Co., Ltd. (Beijing, China). Ascorbic acid, gallic acid and porous amine were purchased from Shillong Science Co., Ltd. (Guangzhou, China). The above drugs are analytically pure.

### 2.2. Sample preparation

The *A. arguta* used in the preparation of NFC juice conformed to GB 2760, GB 2761, GB 2762 and GB 2763 (Chinese national standard code). A.arguta was cleaned by vibration washing method. After sterilisation and crushing the juice was squeezed using a sterile filter cloth (sieve size of about 48 μm). The juice was subsequently homogenized and packed in vacuum bags (50 mL each) and then placed in a refrigerator at 4 °C to await sterilisation.

### 2.3. Sterilisation process

After screening, four of the most widely used juice sterilisation methods on the market were selected for comparative analysis with the unsterilized group (CK): ultraviolet (UV), ultrasound (US), ultrahigh pressure (UHP), and low temperature long time (LTLT) (Fig. 1). UV: irradiated with an ultraviolet sterilizer (Suzhou Antai Air Technology Co., Ltd., China) at a wavelength of 253 nm for 20 min (Jeon & Ha, 2019); US: Ultrasonic sterilizer (Shanghai Bilang Instrument Manufacturing Co., Ltd., China) at 400w, 12 min (Alongi et al., 2019); UHP: use ultra-autoclave (Shanxi Lidefu Technology Co., Ltd., China), 300 MPa, 10 min, cycle 2 times (Zhang et al., 2023); LTLT: Constant temperature water bath (Shanghai Boxun Industrial Co., Ltd. Medical Equipment Factory, China) 60 °C, 25 min (Falcó et al., 2020). After sterilisation, the juice samples are quickly placed in a cold water bath and cooled to room temperature for subsequent studies.

### 2.4. Determination of microorganisms

The aerobic plate count (APC), yeasts and moulds (Y&M), and *Escherichia coli* (*E. coli*) were determined using the methods of GB 4789.2–2022, GB 4789.15–2016, and GB 4789.3–2016 (Chinese national standard code), respectively. Specific steps: the juice was diluted in different series with sterile saline, and 1 mL of each of the three suitable dilutions was selected and added to a sterile petri dish. Microbial inoculation was performed using the inverted plate method. APC

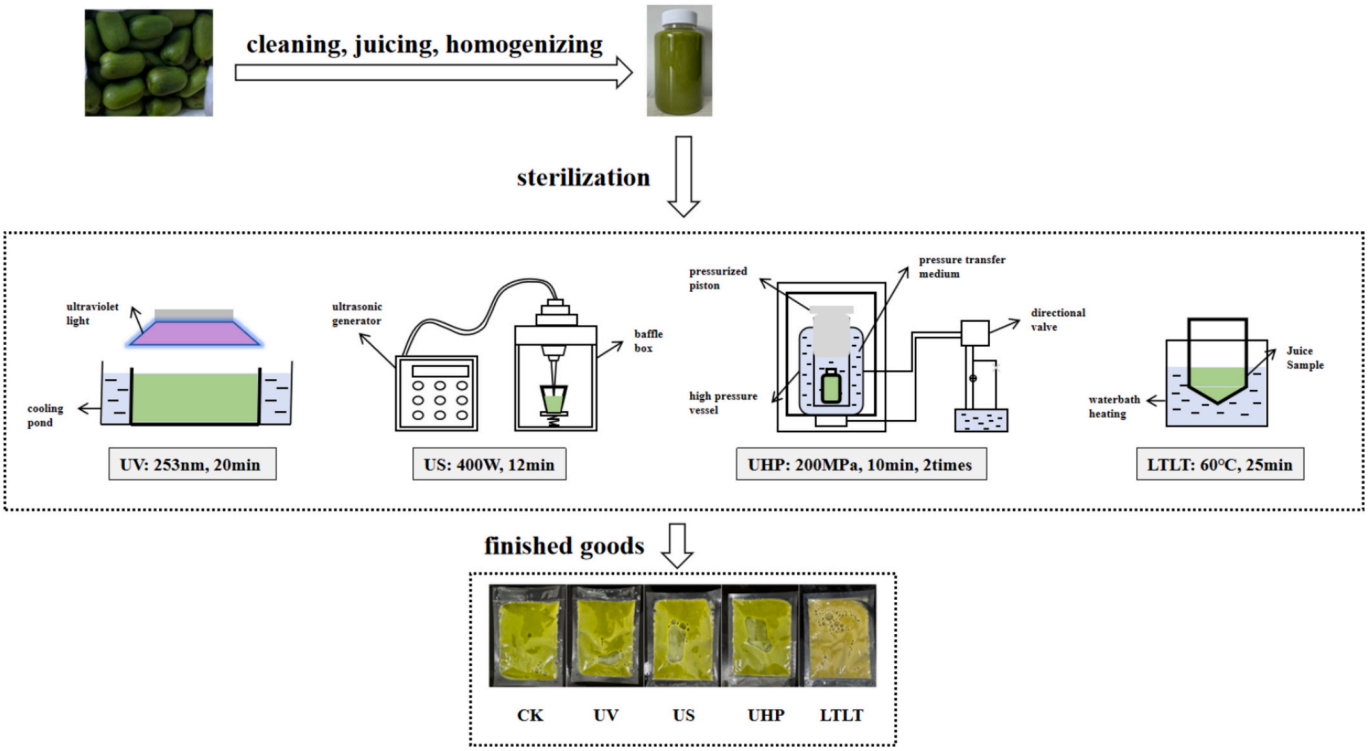


**Fig. 1.** Four sterilisation methods were used to treat NFC *A. arguta* juice.

and *E. coli* were incubated with plate count agar (PCA) and violet red bile agar (VRBA) at 37 °C for 48 h and 24 h, respectively; and Y&M were incubated with rose bengal chloramphenicol agar (RBCA) at 28 °C for 5d. were incubated for 5d. Plates with colony numbers between 30 and 300 CFU were selected for counting by APC, and those with colony numbers between 10 and 150 CFU were selected for counting by Y&M and *E. coli*. The results were expressed as the logarithmic value of the number of CFUs per millilitre of NFC *A. arguta* juice (log CFU/mL).

### 2.5. Determination of pH, total soluble solids (TSS), total acid content (TAC) and solid-acid ratio

Juice pH was measured using a pH meter (Shanghai Yidian Scientific Instrument Co., Ltd., China). TSS was measured using an Abbe refractometer (Shanghai Yiwei Instrument Co., Ltd., China). TAC was determined by potentiometric titration using 0.1 mol/L NaOH standard titration solution, when pH 8.2 was the end point of the titration, the volume of consumed NaOH was recorded (Zhu et al., 2020). The solid-acid ratio was obtained as TSS/TAC.

### 2.6. Determination of bioactive ingredients

#### 2.6.1. Chlorophyll

According to the maximum absorption wavelength of chlorophyll *a* and chlorophyll *b*, their absorbance at wavelengths of 645 nm and 663 nm were measured using UV–visible spectrophotometer, respectively, and the chlorophyll content was obtained by calculation. The calculate; one method is as follows:

$$\text{chlorophyll } a : C_a = 12.72 \times A_{663} - 2.95 \times A_{645}$$

$$\text{chlorophyll } b : C_b = 22.88 \times A_{654} - 4.67 \times A_{663}$$

$$\text{total chlorophyll} : C_i = C_a + C_b$$

#### 2.6.2. Total sugars content (TSC), total flavonoids content (TFC), total phenols content (TPC) and ascorbic acid content (AAC)

Phenol-sulfuric acid method was used to measure TSC, aluminum trichloride colorimetric method to measure TFC, and foraminol colorimetric method to measure TPC, and all three methods were quantified by standard curves, and the results of TSC were expressed as g/100 g, the results of TFC were expressed as the equivalent of rutin per 1 mL of fresh juice (μg Rutin/mL FW). TPC results were expressed as gallic acid equivalent per 100 g of fresh juice (mg GAE/100 g FW). AAC was measured using a kit (Qiyi Biotechnology Co., Ltd., China), and the results were expressed as μg/mL. To ensure the accuracy of the measurements, samples from the same batch were selected to repeat the determination three times.

### 2.7. Determination of colour

The CIElab parameters for the NFC *A. arguta* juice were determined using a benchtop spectrophotometer (Shenzhen Sanen Technology Co., Ltd., China), and the instrument should be corrected for black and white before use. The parameters obtained directly by the instrument are L* (luminance), a* (green/red), b* (blue/yellow). The formula for calculating the total colour difference ΔE is as follows:

$$\Delta E = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2}$$

The Browning Index (BI) is calculated as follows (Zhang et al., 2024):

$$BI = 100 \times \frac{x - 0.31}{0.172}$$

$$x = \frac{a^* + 1.75L^*}{5.645L^* + a^* - 3.012b^*}$$

where $L_0$, $a_0$ and $b_0$ are the colour values of the CK group of juices.

### 2.8. Determination of flavor

#### 2.8.1. Electronic nose

In this study, five fruit juice samples were identified by odor detection by cNose electronic nose (Shanghai Baosheng Industrial Development Co., Ltd.). During the test, the same 10 mL of each sample was taken for the test, and the sample was placed in a 40 mL odourless, colourless and transparent headspace injection sample bottle, screwed on the cap, and left to stand for 60 min. According to the principle of solid-gas equilibrium and solid-liquid equilibrium, the gas evolved from the sample after a certain period will fill up the headspace at the upper part of the sample, and this process needs to keep the temperature and humidity of the test environment consistent. The carrier gas is clean air, and the gas present in the sample is pushed through the sensor array at a rate of 1.0 L/min, resulting in a change in sensor conductivity. The measurement phase lasts in the 60s.

#### 2.8.2. SPME and GC–MS analysis

The volatile components were extracted by solid phase microextraction (SPME). 3 mL of the juice sample was placed in a 15 mL headspace vial, and 0.83 g of NaCl and 12 μL of 2-octanol at a concentration of 0.1 mg/mL were added as the internal standard, which was sealed with a PTFE/silicone rubber spacer compression. After equilibrating at 50 °C under constant magnetic stirring for 15 min, the needle of CAR/ DVB /PDMS (50/30 μm, 10 mm) triple composite extraction fibre head was inserted into the headspace vial through the spacer at a depth of 1 cm, and then the extraction fibre head was pushed out, and then the extraction fibre head was withdrawn after extracting for 40 min at 50 °C under constant magnetic stirring, and the extracted sample The extracted sample was subjected to GC–MS.

Chromatographic conditions: Shimadzu QP-2020 gas chromatograph, DB-17 capillary column (60 m × 0.25 mm inner diameter, 0.25 μm film thickness), helium flow rate of 0.8 mL/min, no shunt injection, the starting column temperature of 40 °C was maintained for 3 min, and then the temperature was increased to 120 °C at a rate of 4 °C/min, and then to 240 °C at a rate of 6 °C/min and maintained for 12 min. Then the temperature increased to 120 °C at a rate of 4 °C/min, and then to 240 °C at a rate of 6 °C/min.

Mass spectrometry conditions: ionisation mode EI, electron energy 70 eV, scanning range 35-500 *m/z*, electron source temperature 200 °C, ion source temperature 230 °C.

Comparison of the recorded mass spectra with the NIST 14.0 database for the characterisation of volatile compounds. The Retention index (RI) of the compounds was analyzed against the literature data related to the compounds and the RI of the compounds was calculated according to the following formula:

$$RI = \frac{lgt_{Ri} - lgt_{Rz}}{lgt_{R(z+1)} - lgt_{Rz}} \times 100$$

where: tRi is the retention time/min of component i to be measured; tRz and tR(z + 1) are the retention time/min of the n-alkanes immediately before and after the aroma substance i; z is the number of carbon atoms of the n-alkanes.

The amount of each compound was determined by comparing the peak area of the compound to the peak area of the internal standard substance.

### 2.9. Statistical analysis

The results of microbiological analysis and chemical properties were expressed as the mean of three measurements for each sample, respectively. Results are expressed as mean ± standard deviation. SPSS software (version 22.0; SPSS Inc., Chicago, IL, USA) was used. Differences

were considered statistically significant at $P < 0.05$. Plots were made using Origin 2021 software (OriginLab, Northampton, MA, USA).

## 3. Results and discussion

### 3.1. Analysis of microbiology

Food microbiological testing is essential to ensure food and public health safety and improve product quality. According to the national food safety standard 'Beverage' (GB 7101–2022), the limit value of APC in beverages after sterilisation is <2 lg CFU/mL, the limit value of Y&M is <1.3 lg CFU/mL, and the limit value of *E. coli* is <0 lg CFU/mL. The APC and Y&M indices were determined in samples of NFC *A. arguta* juice without sterilisation treatment to be 2.50 ± 0.10 lg CFU/mL and 2.37 ± 0.06 lg CFU/mL, respectively. All exceeded the safety limits, indicating that the samples present a microbiological safety hazard. In this regard, sterilisation of NFC *A. arguta* juice is a key part of ensuring food safety and extending shelf life. The APC and Y&M of the NFC *A. arguta* juices treated by the four sterilisation methods were reduced to safety limits and *E. coli* was not detected. As shown in Fig. 2, LTLT had the most significant bactericidal effect with 73.20 % reduction in APC. US and UHP bactericidal were more significant with 40.40 % and 54.00 % reduction in APC, respectively ($p < 0.05$). Ultraviolet (UV) sterilisation was unsatisfactory, possibly due to the fact that the solid particles of *A. arguta* NFC juice are large and the turbidity is too high, and this quality characteristic of the juice results in the UV irradiation not being able to penetrate completely into the juice, and the microorganisms not being inactivated effectively (Beaulieu & Obando-Ulloa, 2017). The inactivation of Y&M by the four bactericidal methods ranged from 54.85 % to 81.01 %, and all of them were able to kill Y&M significantly. In terms of the bactericidal effect as a whole, the bactericidal effect of UHP was closer to that of LTLT. UHP mainly uses water as the pressure transfer medium, in addition, the microorganisms in liquid foodstuffs under the combined effect of strong shear and high-speed impact, their physiological structure is destroyed, thus losing biological activity (Emre et al., 2024). Although UHP kills most of the microorganisms in the juice, there are still some stress-resistant microorganisms and spores, such as *Clostridium perfringens*, that can be reactivated during storage of the juice.

### 3.2. Analysis of physical and chemical properties

The effects of different sterilisation methods on the physicochemical indexes of NFC *A. arguta* juice are shown in Fig. 3. The pH of the juice treated by the four methods of sterilisation was not significantly different ($p > 0.05$) from that of CK in the unsterilised group and was maintained between 3.26 and 3.27. This is consistent with the results of the Feijoa juice study (Schmidt et al., 2022). TSS and TAC are important indicators of the sweet and sour taste of fruit juice. TSS refers to the sum of soluble substances in the juice from the free state, mainly including reducing or non-reducing sugars, organic acids, vitamins and so on. As shown in Fig. 3 (B), TSS and TAC of the unsterilised CK group were 9.40 ± 0.11 % and 22.63 ± 0.01 %, respectively, and the values of TSS of the juice were increased after sterilisation treatments by all four methods. Similar results were obtained in apple cloudy juice (Zhu et al., 2022). The significant ($p < 0.05$) change in TSS of the juice after US and UHP treatments could be attributed to the fact that ultrasound and high pressure ruptured the cell wall and cell membrane of the plant, resulting in the release of the internal soluble substances to the outside of the cell, which ultimately led to an increase in the TSS content. The TAC values of all four sterilisation methods were significantly lower ($p < 0.05$) than those of the CK group, with the most significant reduction in the LTLT group. It has been found that heating causes the juice to produce a Maillard reaction, which further depletes amino acids, reducing sugars, and thus lowers the TAC. TSS/TAC directly affects the flavor and organoleptic properties of the juice. It is generally believed that the larger the TSS/TAC, the sweeter the juice is; the smaller the TSS/TAC, the more acidic the juice is. China's Ministry of Agriculture and Rural Development (MARD) stipulates that the TSS/TAC of NFC apple juice should be between 11.0 and 60.0. The TSS/TAC of the juices were significantly increased ($p < 0.05$) after the sterilisation treatment, which means that the sterilised NFC *A. arguta* juices were sweeter in taste than the unsterilised CK group.

### 3.3. Bioactive ingredient analysis

#### 3.3.1. Analysis of chlorophyll

Chlorophyll is a lipophilic compound and a natural photosensitive pigment abundant in fruits and vegetables (Delgado-Pelayo et al., 2014). Chlorophyll is divided into chlorophyll *a* and chlorophyll *b*, of which chlorophyll *a* show blue-green colour and chlorophyll *b* shows yellow-green colour. *A. arguta* is rich in chlorophyll, so it is necessary to study the effect of sterilisation treatment on the change of chlorophyll content in NFC *A. arguta* juices. As shown in Table 1, there was no significant change ($p > 0.05$) in chlorophyll content in UV and UHP groups compared to CK group. The retention rates of chlorophyll *a*, chlorophyll *b* and total chlorophyll were 99.31 %, 98.61 % and 99.05 % in the UV group, respectively. The UHP group was 99.84 %, 98.68 % and 99.41 %, respectively. No significant changes in chlorophyll content were also reported in wheat wort after UV and high pressure treatments (Ali et al.,

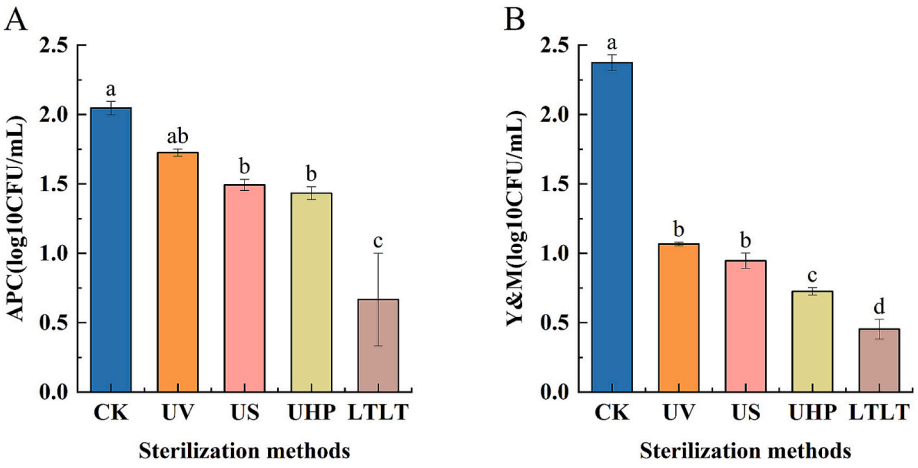


**Fig. 2.** The aerobic plate count (APC) (A) and yeast mould (Y&M) (B) of NFC *A. arguta* juices with different sterilisation methods ($n = 3$). Different letters indicate significant differences between means ($p < 0.05$).

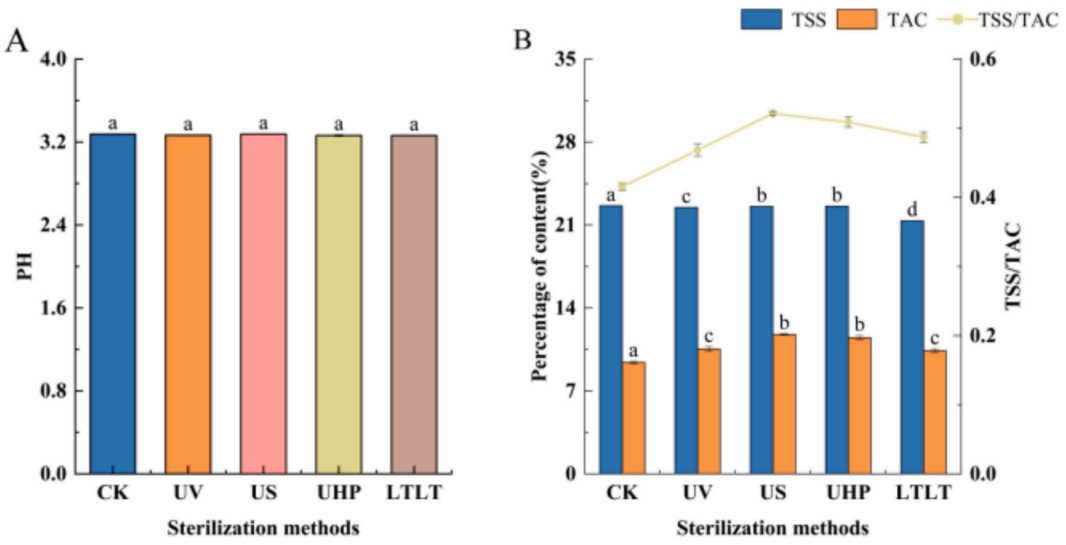


**Fig. 3.** pH (A) and TSS, TAC, TSS/TAC (B) of of NFC *A. arguta* juices with different sterilisation methods (n = 3). Different letters indicate significant differences between means ($p < 0.05$).

**Table 1**
Chlorophyll、TSC、TFC、TPC、AAC of NFC *A. arguta* juices with different sterilisation methods.

| Compounds | Sterilisation methods | | | | |
|---|---|---|---|---|---|
| | CK | UV | US | UHP | LTLT |
| Chlorophyll a (μg/mL) | 45.06 ± 0.50$^{a}$ | 44.75 ±0.85$^{a}$ | 41.11 ±0.46$^{b}$ | 44.99 ±0.36$^{a}$ | 36.09 ±0.49$^{c}$ |
| Chlorophyll b (μg/mL) | 25.81 ± 0.15$^{a}$ | 25.45 ±0.40$^{a}$ | 24.26 ±0.27$^{b}$ | 25.47 ±0.28$^{a}$ | 22.09 ±0.17$^{c}$ |
| Total chlorophyll (μg/mL) | 70.87 ± 0.36$^{a}$ | 70.20 ±1.19$^{a}$ | 65.37 ±0.61$^{b}$ | 70.45 ±0.57$^{a}$ | 58.17 ±0.66$^{c}$ |
| TSC (g/100 g) | 12.08 ± 0.24$^{a}$ | 12.53 ±0.37$^{a}$ | 14.45 ±0.30$^{c}$ | 12.49 ±0.19$^{a}$ | 13.63 ±0.30$^{b}$ |
| TFC (μg Rutin/mL FW) | 15.57 ± 0.42$^{a}$ | 14.52 ±0.17$^{c}$ | 12.70 ±0.18$^{d}$ | 15.02 ±0.19$^{b}$ | 12.03 ±0.09$^{e}$ |
| TPC (mg GAE/100 g FW) | 9.26 ±0.27$^{a}$ | 8.28 ±0.10$^{b}$ | 8.23 ±0.09$^{b}$ | 8.47 ±0.06$^{b}$ | 7.78 ±0.09$^{c}$ |
| AAC (μg/mL) | 174.33 ± 0.70$^{a}$ | 162.67 ±0.93$^{a}$ | 146.00 ±3.07$^{a}$ | 166.00 ±0.89$^{a}$ | 67.67 ±0.61$^{b}$ |

Data are expressed as mean ± SD (n = 3). Different letters in the same row indicate significant differences between means ($p < 0.05$).

2020). The chlorophyll content of the juice was significantly lower ($p < 0.05$) in both the US and LTLT groups compared to the CK group. The loss rates of chlorophyll *a*, chlorophyll *b* and total chlorophyll in the US group were 8.77 %, 6.01 % and 7.76 %, respectively. The loss rates of chlorophyll *a*, chlorophyll *b* and total chlorophyll in the LTLT group were 19.91 %, 14.41 % and 17.92 %, respectively. There is a reasonable explanation for the damaging effect of temperature on chlorophyll: in plants, chlorophyll is encapsulated in thylakoid membranes, and more than 80 % of chlorophyll exists in the form of chlorophyll-protein complexes. This special structure gives chlorophyll good stability, but high temperature treatment degrades the proteins in the complex, leading to chlorophyll loss (Xu et al., 2018).

### 3.3.2. Analysis of TSC, TFC, TPC and AAC

As shown in Table 1, the TSC, TFC, TPC and Vitamin C in the unsterilised CK group were 12.08 ± 0.24 g/100 g, 15.57 ± 0.42 μg Rutin/mL FW, 9.26 ± 0.27 mg GAE/100 g FW and 33.01 ± 0.70 μg/mL, respectively. UV and UHP treatments had no significant effect ($p > 0.05$) on the TSC of the juice, while US and LTLT treatments increased the TSC of the juice by 19.62 % and 12.83 %, respectively. This is mainly because the mechanical effect of ultrasound and the higher temperature will damage the cell wall and promote the hydrolysis of polysaccharides in the cell wall, so that more polysaccharides will be released (Pinelo et al., 2010). All four methods of sterilisation significantly ($p < 0.05$) reduced the TFC in the juice compared to the CK group, with a loss rate of LTLT (22.74 %), US (18.43 %), UV (6.74 %), and UHP (3.52 %) in descending order. This is mainly due to the reduction in the biological activity of polyphenol oxidase (PPO) and peroxidase (POD) in the juice due to the sterilisation process, which results in the loss of flavonoids (Plaza et al., 2011).

All four methods of sterilisation significantly reduced the polyphenol content of NFC *A. arguta* juice ($p < 0.05$), but the loss rates only ranged from 8.53 % to 15.98 %, suggesting that the sterilisation treatments did not cause a more severe loss of polyphenols from the juice. This may be due to the fact that polyphenols in *A. arguta* are predominantly anthocyanin glycosides and phenolic acids, and that polyphenols in *A. arguta* juices are highly biostable when sterilised because of the high stability of acylated anthocyanins and the inter- or intramolecular co-pigmentation of phenolic acids (Macedo et al., 2023).

AAC, as a water-soluble vitamin, is an essential antioxidant molecule in the metabolism of plants and animals and a cofactor for many enzymes (Fenech et al., 2019). The change in AAC content is also one of the key indicators for evaluating processing technology. Of interest, there was no significant change ($p > 0.05$) in the AAC content of *A. arguta* juices treated with the three non-thermal sterilisation methods, UV, US and UHP, compared to the control group, CK, while the loss of AAC was as high as 61.18 % in the thermally sterilised LTLT group. This reduction in the water-soluble vitamin content of heat-treated fruits and vegetables can be attributed to the fact that water-soluble vitamins are more sensitive to temperature, and that an increase in temperature during processing exacerbates the loss of water-soluble vitamins (Odriozola-Serrano et al., 2008).

In conclusion, UV, US and UHP are non-thermal sterilisation techniques, which achieve their sterilizing effect through photolytic reaction, cavitation effect and modification of water and microbial structure in the juice, respectively. Since the majority of bioactive components in fruit juices are heat-sensitive, this makes the non-thermal sterilisation techniques have less effect on them.LTLT treatments are performed at lower temperatures, so the degradation of heat-sensitive components is slower. However, prolonged heating can lead to oxidative or thermal degradation of bioactive components, especially for ascorbic acid and polyphenols. Therefore, non-thermal sterilisation techniques are a better choice in preserving the bioactive components of NFC *A. arguta* juice.

### 3.4. Analysis of colour

The colour of juice is one of the most important indicators of consumer desire to buy and evaluate the quality of juice and is important for the commercial value of juice. A large number of coloured substances such as anthocyanins and chlorophyll in NFC *A. arguta* juice are easily oxidised or degraded after ultrasound or heat treatment. Therefore, it is crucial to investigate the effect of different sterilisation methods on NFC *A. arguta* juice. The CIELAB colour space is widely used to measure the overall colour change during the processing and storage of fruit juices. Fig. 4 (A), (B) and (C) represent the changes in CIELAB parameters of NFC *A. arguta* juice after different sterilisation treatments. As shown in Fig. 4 (A), a* (green-red) and b* (blue-yellow) represent the colour change of the juice. The a* and b* values of the juices of the UV, US and LTLT groups were higher than those of the unsterilised CK group, indicating that all three methods of sterilisation increased the green and yellow colour of the juices. The most significant ($p < 0.05$) change in juice colour was observed after LTLT treatment (a* values increased from −0.77 to −0.26; b* values increased from 0.38 to 0.75), and this result is consistent with the change in juice colour observed by the naked eye. The a* value of the juice in the UHP group was essentially unchanged and the b* value was reduced to 0.29, indicating that the UHP treatment imparted a more emerald green colour to the juice. This is consistent with the results of changes in chlorophyll content in the juice after UHP treatment. As shown in Fig. 4(B) and (C), although the L* values of the UV, US and UHP groups fluctuated compared with those of the CK group, the ΔE values were lower, indicating that the naked eye could not identify any change in the colour of the juice after treatment with these three sterilisation methods. The L* values of LTLT-treated juices were significantly higher ($p < 0.05$) and ΔE was larger, indicating that the colour of the juices differed significantly from that of the unsterilised juices. This may be due to isomerisation of carotenoids and loss of chlorophyll in the juice because of heat treatment, leading to a bright, yellowish colour. Browning reaction is a common phenomenon in juice processing. In general, the browning reaction involves caramelisation, Maillard reaction and degradation of ascorbic acid (AA) (Aghajanzadeh et al., 2023). Considering the lower pH of NFC *A. arguta* juice, the browning reaction of the juice may be mainly related to the degradation of AA. As shown in Fig. 4 (D), the BI values of the juices in the UV, US and LTLT groups increased, indicating browning of the juices. The browning was not significant in the US group and significant ($p < 0.05$) in the UV and LTLT groups, which is consistent with the previous changes in a*, b*, and L* values. UV and LTLT treatments can promote oxidative reactions and activate enzymes that lead to changes in pigments or other compounds in the juice, resulting in browning. The degree of juice browning decreased significantly after UHP treatment ($p < 0.05$) and the BI value was lower than that of the CK group (from 351.16 ± 1.49 to 246.14 ± 1.48). This is due to the fact that UHP treatment can reduce the degradation of chlorophyll, inhibit the activity of related enzymes, reduce oxidative reactions, and regulate the stability of pigments to a certain extent, so that the juice maintains or presents a more vivid green colour.

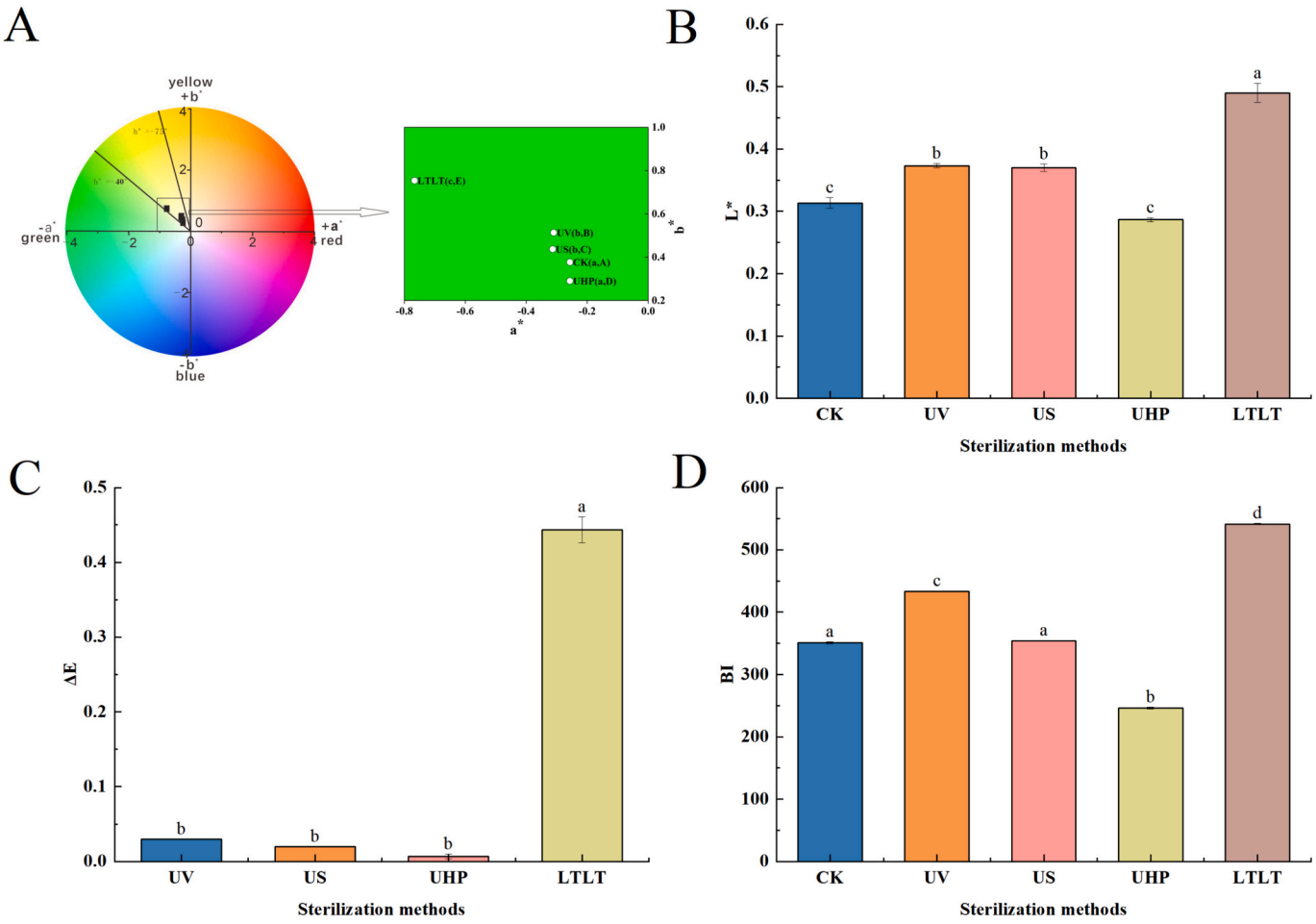


**Fig. 4.** Chromaticity distribution (A), L*: brightness (B), ΔE: total colour difference (C) and BI: browning index (D) of NFC *A. arguta* juices with different sterilisation methods (n = 3). Different letters indicate significant differences between means ($p < 0.05$).

### 3.5. Electronic nose analysis

#### 3.5.1. Analysis of the electronic nose response value

The electronic nose was used to detect the effects of different sterilisation methods on the aroma of NFC *A. arguta* juice and to establish radargrams. As shown in Fig. 5(A), from the radargrams of five groups of NFC *A. arguta* juice, it can be seen that the sensing trend of different sensors on the flavor substances of juice samples with different sterilisation methods has consistency, but there are differences in the sensing data, which indicates that there are similarities in the categories of the flavor substances in different juices, but at the same time there are differences in the contents of the different flavor substances, and the differences in the contents of the different flavor substances are also relatively obvious.The strongest response value of Sn3 The response values of Sn2, Sn7, Sn12 and Sn9 of *A. arguta* juice after UHP and LTLT treatments were significantly different from those of CK group, which indicated that the loss of flavor substances in the juice was caused by the high-pressure and heat treatments. The response values of US treatment were close to those of CK group. Response values were close to those of CK group. The response profiles of the juices in the UV group were significantly higher than those of the other groups, suggesting that UV irradiation improves the aroma of NFC *A. arguta* juices, and a similar phenomenon was observed in the study of oolong tea (Wang et al., 2023).

#### 3.5.2. Different sterilisation methods electronic nose identification

The aroma of NFC *A. arguta* juice showed great differences depending on the sterilisation method. However, the NFC *A. arguta* juice treated with different sterilisation methods could not be well distinguished by observing the sensor response values alone. In order to better distinguish them, this study used dimensionality reduction analysis to summarize the effective information and exclude the useless and redundant information, so as to achieve efficient feature extraction of multi-dimensional information and visualization of low-dimensional data. Mainly, the electronic nose was combined with LDA (Linear Discriminant Analysis) and PCA (Principal Component Analysis). The LDA downscaling analysis is supervised downscaling, and it can be seen through the LDA downscaling analysis graph in Fig. 6(A) that the variance contributions of principal components PC 1 and PC 2 are 95.94 % and 2.73 %, respectively, and the cumulative variance contribution is 98.67 %. The odors of fruit juices treated with different sterilisation methods could be completely distinguished by the electronic nose, and the sample odor data did not cross each other, the respective boundaries were clear, and the odors showed variability among the samples. The odor information of the five samples was further validated by unsupervised analysis.

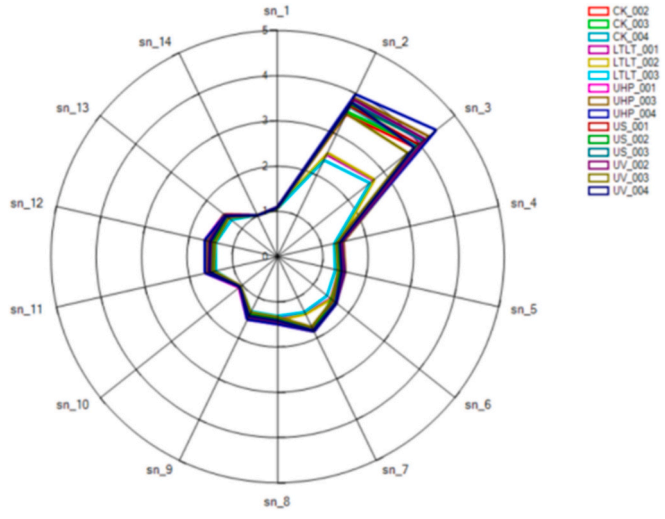


**Fig. 5.** Response of electronic nose radar in NFC *A. arguta* juices after different sterilisation methods (n = 3).

PCA simplifies the variables by selecting a few composite indicators in place of the original information without losing most of the odor information from the sample (Song et al., 2023). The horizontal coordinate indicates the percentage of overall information accounted for by the first principal component, and the vertical coordinate indicates the percentage of overall information accounted for by the second principal component. From Fig. 6(B), we can see that the variance contributions of PC1 and PC2 are 76.52 % and 14.98 %, respectively, and the cumulative variance contribution is 91.50 %, which basically represents all the information of the samples, and the data are valid by principal component analysis. From Fig. 6 (B) and (C), we can see that LTLT and UHP treated juice odor is far away from the other, CK group and US and UV juice samples odor signals between the region without cross and close spacing, the odor has a certain degree of differentiation and similarity. There is a crossover between the signals of the US and UV gas samples, the use of analysis of variance to further validate the odor characteristics of the five samples. The ANOVA results are shown in Table S1 below, with highly statistically significant differences between individual samples. In terms of multiple comparisons (S2), the CK samples were significantly different from the LTLT samples and the UHP samples, and not significantly different from the US samples and the UV samples; the LTLT samples were significantly different from the UHP, US, and UV, and the UHP was significantly different from the US samples and the UV samples; and the US samples were not significantly different from the UV samples. Overall, the use of UV and US to sterilize the juices resulted in juices that were closer to the flavor of the control, while UHP and LTLT had a greater effect on the flavor of the juices.

#### 3.5.3. Classification modeling and cluster analysis

PCA-kNN is a “hybrid” classification method that combines a linear approach (PCA) and a nonlinear approach (kNN). Specifically, PCA is used to remove some uninformative gradients and capture the underlying structure of the training dataset using some new variables called principal components. kNN makes full use of the maximal margin hyperplane to give the best generalization performance in the PCA-transformed space (Serpen & Aghaei, 2018). The PCA-kNN classification model is shown in Fig. 7(A), and based on the image all the sterilisation methods can be recognized correctly. According to the model accuracy analysis in Fig. 7 (B), the accuracy of the model is 1 (the closer to 1 indicates the higher accuracy). This indicates that the present classification model can basically clearly distinguish the differences between different juice samples. Using this model, predictions can be made for NFC *A. arguta* juice samples treated with unknown sterilisation methods. From the cluster analysis dendrogram in Fig. 7(C), it can be clearly seen that the flavor of NFC *A. arguta* juice treated by LTLT sterilisation is more obviously different from the flavor of other samples. This is similar to the results of the heat-treated apple juice study (Zhu et al., 2022).

### 3.6. Identification of volatile components

A total of 64 volatile compounds were detected by SPME-GC–MS. These included 9 esters, 17 alcohols, 18 aldehydes, 9 ketones, 6 alkenes and 5 other volatile compounds (Table 2). Alcohol has low odor activity and can be present at low concentrations in fruits in the form of glycosidic incorporation. A total of 17 alcohols were detected in the CK group, with a total amount of 3446.93 ± 0.36 μg/L. The highest content was 3-Octanol, which was mainly a contributor to the rose and orange flavours. The contents of 3-Octanol were reduced to different degrees after the sterilisation treatment, and it was not even detected after LTLT treatment, indicating that the heat resistance of 3-Octanol was poor. Overall, the stability of alcohols in NFC *A. arguta* juices was poor, and different sterilisation methods would cause the loss of alcohols. Esters are important volatile compounds that give fruit juice its ‘fruity’ quality

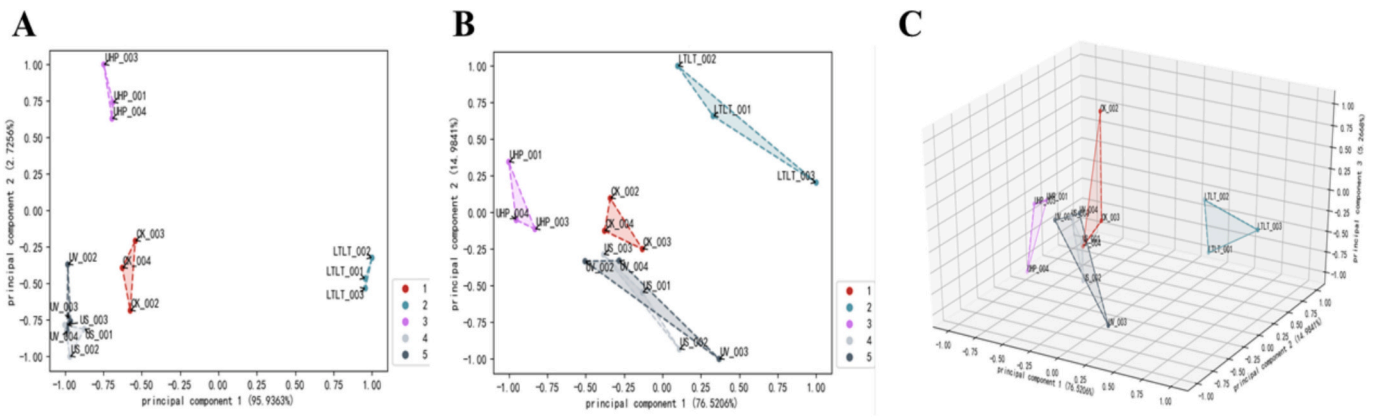


**Fig. 6.** LDA analysis of 2D result plots (A), PCA analysis of 2D result plots (B), and PCA analysis of 3D result plots (C) of NFC *A. arguta* juices with different sterilisation methods (n = 3).

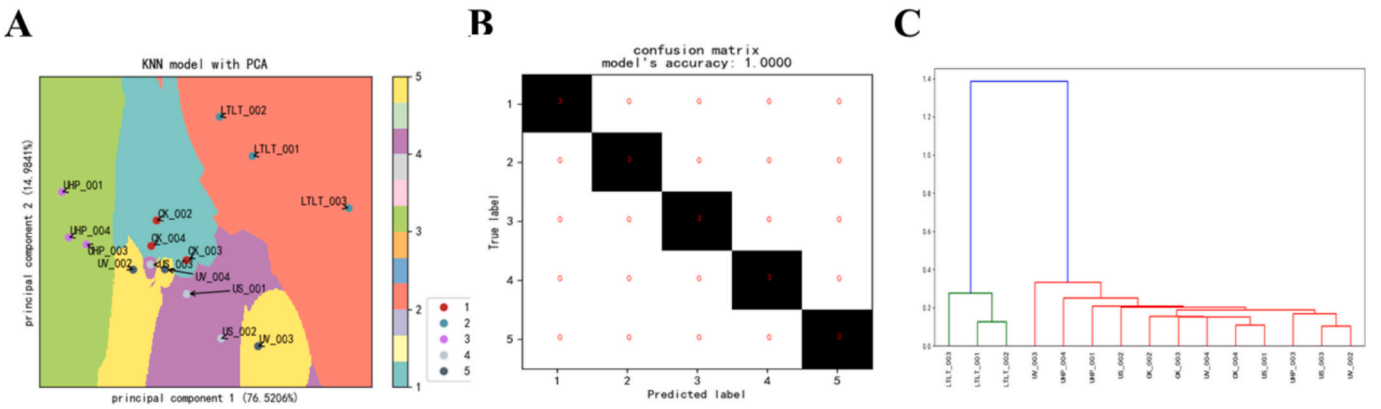


**Fig. 7.** PCA-KNN classification modeling (A), accuracy analysis of PCA-KNN classification models (B), and cluster dendrogram (C) of NFC *A. arguta* juices with different sterilisation methods (n = 3).

(Lara et al., 2008). Although the total ester content of NFC *A. arguta* juices was slightly reduced after sterilisation, there were no significant differences between the four methods of sterilisation.

Changes in specific volatile compounds can be seen through heat maps (Fig. 8). Compared with the control, the volatile compounds in the UHP and LTLT treated juices changed more significantly in terms of type and content, which is consistent with the results of the electronic nose analysis. The main contributors to the aroma of *A. arguta* were volatile aldehydes (Garcia et al., 2011). The content of aldehydes in unpasteurised NFC *A. arguta* juices was 6539.54 ± 0.28 μg/L. Oxidative degradation of unsaturated fatty acids is the main cause of aldehyde formation (Chen et al., 2017). Among the 18 aldehydes identified, Nonanal was the most abundant, followed by 2-Decenal, (*E*)-, which imparted a citrus aroma to the NFC *A. arguta* juices. The aldehydes of the juice did not undergo any significant change in total amount after UV and US treatments, whereas the total aldehydes content of the juice was reduced by UHP and LTLT treatments, accompanied by the production of some new compounds. This may be due to the activation of some flavor precursors or the release of volatile compounds because of high pressure and high temperature.

Alcohol has low odor activity and can be present at low concentrations in fruits in the form of glycosidic incorporation. A total of 17 alcohols were detected in the CK group, with a total amount of 3446.93 ± 0.36 μg/L. The highest content was 3-Octanol, which was mainly a contributor to the rose and orange flavours. The contents of 3-Octanol were reduced to different degrees after the sterilisation treatment, and it was not even detected after LTLT treatment, indicating that the heat resistance of 3-Octanol was poor. Overall, the stability of alcohols in NFC *A. arguta* juices was poor, and different sterilisation methods would cause the loss of alcohols. Esters are important volatile compounds that give fruit juice its 'fruity' quality (Lara et al., 2008). Although the total ester content of NFC *A. arguta* juices was slightly reduced after sterilisation, there were no significant differences between the four methods of sterilisation.

In summary. Although sterilisation can cause changes in the volatile components of NFC *A. arguta* juices, this problem can be minimally circumvented by choosing an appropriate sterilisation method. In addition, the operating conditions of the sterilisation method will also have an impact on the juice aroma, such as ultrasonic power, ultrahigh pressure time and heating temperature. More in-depth studies are needed to better understand the effects of these factors on juice aroma.

## 4. Conclusion

UV, US, UHP and LTLT treatments had significant effects on microbiology, physicochemical properties, bioactive components, static rheology, colour and flavor of NFC *A. arguta* juice. After the four sterilisation treatments, APC, Y&M and *E. coli* in the juices met the biosafety standards, pH of the juices did not change significantly, TSS increased slightly in all cases and TAC decreased slightly. UV and UHP treatments had no significant effect on the bioactive components of the juice compared to US and LTLT. In addition, UV and UHP treatments retained the colour of the juice better than other sterilisation methods. The results of the electronic nose combined with SPME-GC–MS showed that the UV and US treatments resulted in more flavorful juices, close to control, while the UHP and LTLT treatments resulted in a loss of juice

**Table 2**
The levels of volatile components in NFC *A. arguta* juices after different sterilisation methods.

| RI[a] | Volatile compound | Content (μg/L) | | | | | ID method[d] |
|---|---|---|---|---|---|---|---|
| | | CK | UV | US | UHP | LTLT | |
| **Salts** | | | | | | | |
| 984 | Acetic acid, hexyl ester | 498.09 ± 0.02[c] | 421.51 ± 0.13 | 466.22 ± 0.56 | 322.15 ± 0.02 | 367.87 ± 0.01 | MS, RI |
| 1060 | Benzoic acid, methyl ester | 554.14 ± 0.32 | 502.61 ± 0.03 | 531.23 ± 0.06 | 476.65 ± 0.02 | 513.23 ± 0.02 | MS, RI |
| 1183 | Octanoic acid, ethyl ester | 315.60 ± 0.35 | 357.67 ± 0.15 | 262.65 ± 0.03 | 142.73 ± 0.10 | 277.18 ± 0.01 | MS, RI |
| 1381 | Decanoic acid, ethyl ester | 273.78 ± 0.53 | 188.02 ± 0.45 | 198.46 ± 0.01 | 604.14 ± 0.03 | 224.72 ± 0.11 | MS, RI |
| 1680 | Methyl tetradecanoate | 84.02 ± 0.42 | 80.83 ± 0.02 | 83.24 ± 0.01 | 85.64 ± 0.12 | 103.07 ± 0.33 | MS, RI |
| 1580 | Dodecanoic acid, ethyl ester | 75.84 ± 0.38 | 71.04 ± 0.42 | 66.23 ± 0.12 | 73.44 ± 0.56 | 72.11 ± 0.78 | MS, RI |
| 1908 | 1,2-Benzenedicarboxylic acid, bis(2-methylpropyl) ester | 362.01 ± 0.41 | 305.52 ± 0.22 | 243.12 ± 0.08 | 366.82 ± 0.74 | 346.38 ± 0.02 | MS |
| 1878 | Hexadecanoic acid, methyl ester | 110.66 ± 0.01 | 178.64 ± 0.03 | 136.26 ± 0.18 | 117.88 ± 0.27 | 144.85 ± 0.58 | MS, RI |
| 1176 | Pentafluoropropionic acid, decyl ester | 166.39 ± 0.42 | ND[b] | ND | ND | ND | MS |
| **Alcohols** | | | | | | | |
| 1059 | Eucalyptol | 519.33 ± 0.52 | 541.19 ± 0.24 | 503.70 ± 0.02 | 387.78 ± 0.01 | 382.25 ± 0.01 | MS, RI |
| 1143 | L-alph-Terpineol | 596.55 ± 0.45 | 541.19 ± 0.05 | 609.28 ± 0.04 | 396.27 ± 0.01 | 593.66 ± 0.78 | MS, RI |
| 969 | 1-Octen-3-ol | 230.33 ± 0.45 | 565.26 ± 0.76 | 236.52 ± 0.42 | 232.74 ± 0.22 | 194.35 ± 0.02 | MS, RI |
| 979 | 3-Octanol | 638.12 ± 0.38 | 215.77 ± 0.01 | 421.84 ± 0.01 | 614.06 ± 0.12 | ND | MS, RI |
| 1082 | Linalool | 123.00 ± 0.05 | 450.86 ± 0.86 | 102.03 ± 0.40 | 98.94 ± 0.06 | 91.95 ± 0.57 | MS, RI |
| 1137 | 3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, (*R*)- | 358.88 ± 0.45 | 109.11 ± 0.33 | ND | 186.23 ± 0.56 | 249.24 ± 0.17 | MS |
| 1094 | (*S*)-(+)-6-Methyl-1-octanol | 145.92 ± 0.03 | ND | 98.46 ± 0.01 | 121.86 ± 0.02 | 93.62 ± 0.85 | MS |
| 1228 | 3,6-Octadien-1-ol, 3,7-dimethyl-, (*Z*)- | 269.66 ± 0.76 | 143.51 ± 0.51 | 138.60 ± 0.70 | 245.60 ± 0.05 | 111.92 ± 0.63 | MS |
| 1228 | 2,6-Octadien-1-ol, 3,7-dimethyl-, (Z)- | 187.00 ± 0.01 | 218.77 ± 0.02 | 134.07 ± 0.32 | ND | ND | MS |
| 995 | 1-Heptanol | 93.20 ± 0.01 | 137.57 ± 0.05 | ND | ND | ND | MS, RI |
| 1067 | 2-Octen-1-ol, (*E*)- | 96.82 ± 0.07 | 95.61 ± 0.52 | 107.45 ± 0.33 | 104.04 ± 0.17 | 86.03 ± 0.32 | MS, RI |
| 2143 | 6,10,14-Hexadecatrien-1-ol, 3,7,11,15-tetramethyl-, [R-(E, E)]- | 76.05 ± 0.03 | 99.23 ± 0.44 | 62.48 ± 0.35 | 71.23 ± 0.08 | ND | MS |
| 2153 | n-Nonadecanol-1 | 112.07 ± 0.05 | 78.45 ± 0.02 | 75.41 ± 0.04 | ND | ND | MS |
| 1710 | 2,6,10-Dodecatrien-1-ol, 3,7,11-trimethyl- | ND | 222.58 ± 0.54 | ND | ND | 74.48 ± 0.08 | MS |
| 770 | 1-Hexen-3-ol | ND | 158.73 ± 0.64 | 497.67 ± 0.35 | ND | ND | MS |
| 1258 | 1-Decanol | ND | ND | 387.63 ± 0.32 | 145.82 ± 0.86 | ND | MS, RI |
| 1276 | Bicyclo(3.1.1)heptane-2,3-diol, 2,6,6-trimethyl- | ND | ND | ND | ND | 1208.17 ± 0.21 | MS |
| **Aldehydes** | | | | | | | |
| 982 | Benzaldehyde | 424.74 ± 0.42 | ND | 412.67 ± 0.04 | 298.67 ± 0.01 | 691.39 ± 0.02 | MS, RI |
| 1005 | Octanal | 221.42 ± 0.96 | 465.62 ± 0.02 | 256.52 ± 0.01 | 173.40 ± 0.42 | 441.64 ± 0.86 | MS, RI |
| 921 | 2,4-Heptadienal, (E, *E*)- | 509.23 ± 0.41 | 299.55 ± 0.32 | 416.56 ± 0.01 | 289.64 ± 0.01 | 537.20 ± 0.02 | MS, RI |
| 1112 | 2-Nonenal, (E)- | 352.82 ± 0.02 | 448.15 ± 0.47 | 243.59 ± 0.44 | 322.37 ± 0.63 | 330.34 ± 0.55 | MS, RI |
| 1204 | Decanal | 407.91 ± 0.03 | 319.44 ± 0.24 | 350.77 ± 0.07 | 345.46 ± 0.86 | 377.53 ± 0.58 | MS, RI |
| 1212 | 2-Decenal, (E)- | 1099.58 ± 0.36 | 383.05 ± 0.24 | 993.46 ± 0.15 | 1161.14 ± 0.09 | 1213.66 ± 0.02 | MS, RI |
| 1013 | 2-Octenal, (E)- | 312.02 ± 0.56 | 1024.93 ± 0.79 | 273.89 ± 0.11 | 237.59 ± 0.35 | 425.74 ± 0.12 | MS, RI |
| 1120 | 2,6-Nonadienal, (E, *Z*)- | 110.20 ± 0.03 | 354.85 ± 0.01 | 95.41 ± 0.01 | ND | 98.84 ± 0.02 | MS, RI |
| 1220 | 2,4-Decadienal, (E, *E*)- | 226.86 ± 0.75 | 116.98 ± 0.35 | 208.53 ± 0.42 | ND | 218.26 ± 0.21 | MS, RI |
| 1104 | Nonanal | 1271.25 ± 0.02 | 1139.56 ± 0.34 | 1089.67 ± 0.11 | 1118.81 ± 0.02 | ND | MS, RI |
| 1174 | 2,6-Octadienal, 3,7-dimethyl-, (E)- | ND | ND | 150.56 ± 0.01 | ND | 140.80 ± 0.05 | MS |
| 1311 | 2-Undecenal | 844.86 ± 0.68 | 776.52 ± 0.35 | 708.61 ± 0.75 | 956.45 ± 0.06 | ND | MS, RI |
| 913 | 2-Heptenal, (E)- | 171.22 ± 0.42 | 140.36 ± 0.68 | 138.91 ± 0.45 | ND | 191.61 ± 0.05 | MS, RI |
| 1303 | 1-Cyclohexene-1-acetaldehyde, 2,6,6-trimethyl- | 136.73 ± 0.02 | 89.65 ± 0.01 | 78.45 ± 0.75 | ND | ND | MS |
| 814 | 2-Hexenal, (E)- | 162.83 ± 0.03 | ND | ND | ND | ND | MS, RI |
| 1174 | Citral | 287.87 ± 0.68 | ND | ND | ND | ND | MS, RI |
| 913 | 2-Heptenal, (*Z*)- | ND | ND | 125.70 ± 0.42 | ND | ND | MS, RI |
| 1204 | 1-Cyclohexene-1-carboxaldehyde, 2,6,6-trimethyl- | ND | ND | ND | 318.60 ± 0.27 | ND | MS |
| **Ketones** | | | | | | | |
| 938 | 5-Hepten-2-one, 6-methyl- | 698.6 ± 0.03 | 756.32 ± 0.01 | 823.83 ± 0.06 | 691.68 ± 0.02 | ND | MS, RI |
| 1321 | 2-Undecanone, 6,10-dimethyl- | 134.68 ± 1.34 | 96.53 ± 0.67 | 88.04 ± 0.73 | 312.45 ± 1.45 | 172.04 ± 1.09 | MS, RI |
| 1429 | alpha-Ionone | 306.26 ± 0.34 | 312.56 ± 0.57 | 305.4 ± 0.13 | ND | 171.42 ± 0.78 | MS, RI |
| 1540 | beta-Oplopenone | 654.61 ± 0.67 | 663.52 ± 1.36 | 618.56 ± 0.46 | ND | ND | MS, RI |
| 1884 | 2,15-Hexadecanedione | 90.92 ± 0.28 | ND | ND | ND | ND | MS, RI |
| 1440 | 2-Buten-1-one, 1-(2,6,6-trimethyl-1,3-cyclohexadien-1-yl)-, (E)- | 103.38 ± 0.87 | ND | ND | 233.75 ± 0.47 | ND | MS |
| 1420 | 5,9-Undecadien-2-one, 6,10-dimethyl-, (Z)- | 1338.22 ± 1.19 | ND | ND | ND | ND | MS |
| 1420 | 5,9-Undecadien-2-one, 6,10-dimethyl- | 1338.22 ± 0.84 | ND | ND | ND | 70.06 ± 0.09 | MS |
| 1457 | trans-beta-Ionone | ND | ND | ND | ND | 381.45 ± 1.15 | MS, RI |
| Alkenes | | | | | | | |
| 888 | 1,3,5,7-Cyclooctatetraene | 585.15 ± 0.67 | 596.32 ± 0.37 | 622 ± 0.58 | 399.53 ± 0.48 | 753.6 ± 0.74 | MS, RI |
| 1018 | D-Limonene | 320.03 ± 0.27 | 296.51 ± 0.84 | 263.45 ± 0.38 | ND | 322.79 ± 1.06 | MS, RI |
| 1023 | Cyclohexene, 3-methyl-6-(1-methylethylidene)- | 766.39 ± 0.84 | ND | ND | ND | 658.74 ± 0.49 | MS |
| 1140 | 1-Undecene, 7-methyl- | 221.61 ± 0.74 | 210.33 ± 1.85 | 194.99 ± 0.68 | ND | 142.9 ± 0.38 | MS, RI |
| 968 | 2-Octene, 2-methyl-6-methylene- | 300.57 ± 0.66 | 296.54 ± 0.08 | 266.34 ± 1.37 | 254.89 ± 1.22 | 470.55 ± 0.96 | MS |
| 1052 | Cyclohexene, 1-methyl-4-(1-methylethylidene)- | ND | ND | 623.37 ± 0.29 | ND | ND | MS |

(*continued on next page*)

**Table 2** (*continued*)

| RI[a] | Volatile compound | Content (μg/L) | | | | | ID method[d] |
|---|---|---|---|---|---|---|---|
| | | CK | UV | US | UHP | LTLT | |
| **Others** | | | | | | | |
| 1062 | Cyclopropane, 1-(2-methylbutyl)-1-(1-methylpropyl)- | 241.4 ± 0.75 | 223.67 ± 0.87 | 250.63 ± 0.11 | ND | ND | MS |
| 1326 | Phenol, 3-methyl-6-propyl- | 172.64 ± 0.08 | 171.56 ± 0.03 | 174.16 ± 0.31 | ND | 329.36 ± 0.77 | MS |
| 1668 | Butylated Hydroxytoluene | 233.41 ± 0.05 | 203.48 ± 1.19 | 186.55 ± 0.63 | 559.32 ± 0.28 | 195.1 ± 0.89 | MS |
| 1968 | n-Hexadecanoic acid | 194.41 ± 1.11 | 119.66 ± 1.67 | 113.1 ± 1.85 | ND | 280.11 ± 0.07 | MS |
| 1106 | Oxirane, octyl- | ND | ND | ND | ND | 1434.91 ± 1.96 | MS |

a RI (retention index): Standards of n-alkanes ($C_{8-}C_{20}$) were used for RI conversion.
b ND: Not detected.
c Values are presented as mean ± standard deviation ($P < 0.05$).
d Identification methods: MS, RI.

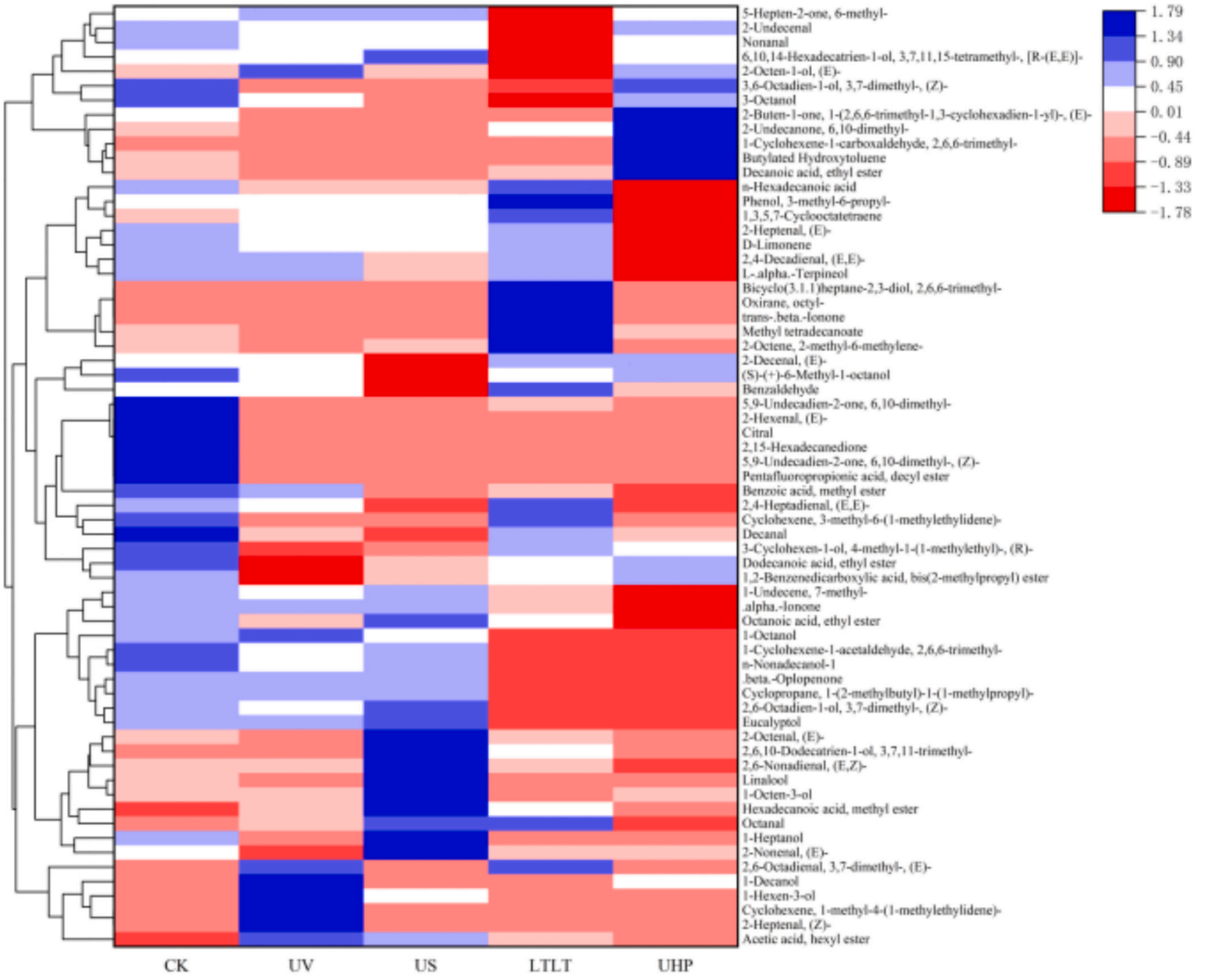


**Fig. 8.** Heatmap visualization of NFC *A. arguta* juices with different sterilisation methods.

flavor. Taken together, the use of UV sterilisation in NFC juices has clear advantages, especially in improving juice safety, extending shelf life, and preserving nutrition and flavor. Although the effectiveness of UV sterilisation may be limited in some turbid juices, UV remains a promising treatment method by optimizing the process and using it in combination with other technologies. However, further research and optimization of the technical parameters of UV sterilisation are needed for future commercial applications to improve its treatment efficiency and to accommodate more types of juices.

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## CRediT authorship contribution statement

**Lina Chen:** Project administration, Funding acquisition. **Tienan Wang:** Software, Methodology, Conceptualization. **Yuhan Sui:** Writing – original draft, Supervision, Data curation. **Mengjuan Gong:** Visualization. **Meijia Li:** Investigation. **Xinning Du:** Writing – review & editing. **Shuyu Zhang:** Visualization.

## Declaration of competing interest

The 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.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2025.102354.

## Data availability

The authors do not have permission to share data.

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