

Supplementary material

1. The near-freezing temperature (NFT) storage system

A modified cold storage system was applied in the research (Figure S1). The NFT storage system mainly contains a cabinet door (3), a cabinet (16), refrigeration equipment, temperature alarm device (14) and water drainage and ventilation equipment (10).

As shown in Figure S1, drainage ventilation equipment including drainage pipe (11), ventilation duct (10) and solenoid valve (12). Storage room (8) is equipped with ventilation duct (10) on the top side, drainage duct (11) on the bottom side, there are solenoid valves (12) equipped on ventilation duct (10) and drainage duct (11). Storage room (8) is equipped with load platforms (13) at the bottom, load platforms (13) are equipped with a compartment below to collect condensate, and then discharged to outside through drainage duct (11). The ventilation and drainage functions can be performed by controlling the open and close of the solenoid valve (12), and the condensate and ethylene produced during the storage can be drained to the outside at regular intervals.

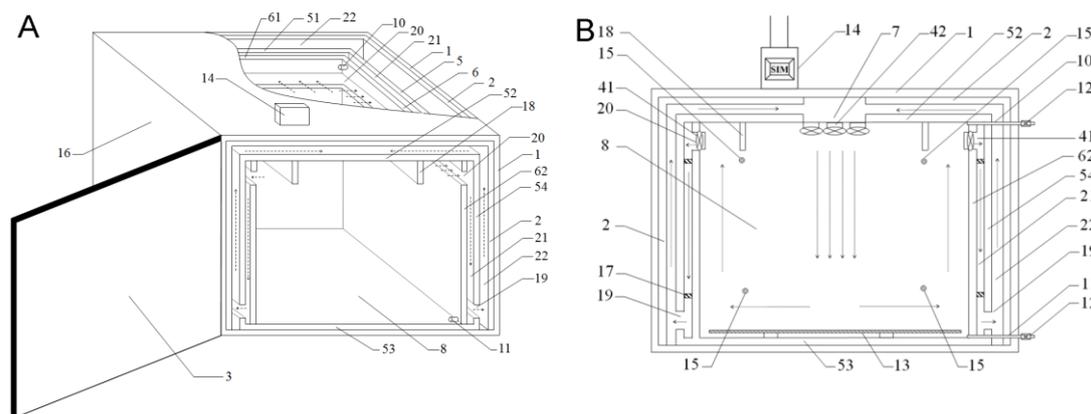


Figure S1 Schematic diagram of near freezing temperature storage machine. Structural representation (A) and section view (B). Note: 1: insulation board, 2: refrigeration panel, 3: cabinet door, 41: first stream fan, 42: second stream fan, 5: first insulation, 51: first back panel, 52: top panel, 53: bottom panel, 54: first side panel, 6: second insulation, 61: second back panel, 62: second side panel, 7: air inlet, 8: storeroom, 10: ventilation duct, 11: drainage duct, 12: solenoid valve, 13: carrier table, 14: alarm device, 15: temperature sensor, 16: cabinet, 17: support bar, 18: baffle, 19: lower air vent, 20: upper air vent, 21: first channel, 22: second channel

As shown in **Figure S1**, several temperature sensors (15) are placed at various corners of the storage room (8) to monitor temperature changes. The alarm device (14) is disposed on the exterior of the cabinet (16), which contains a SIM card, and it is connected to the temperature sensors (15). If severe temperature fluctuations are detected during storage, an alarm is raised via the alarm device (14).

The NFT storage system in this research containing two sets of temperature control approaches. Temperature changes are regulated by the refrigeration plate (2) and flow fans (41, 42) together, both can minimize the temperature fluctuation of the storage room and can reduce the switching frequency of refrigeration machine, to protect the

compressor. The circulating airflow pattern generated by the device creates a small wind circulating airflow inside the storage room to ensure uniformity of temperature in the storage room. The drainage and ventilation equipment can regularly discharge the condensed water and ethylene gas produced during the storage to the outdoors. The alarm device can provide a low temperature alarm and automatically take emergency measures to avoid freezing damage to fruit and vegetables, which can be notified to the administrator through the SIM phone call function.

2. The determination of fruit NFT storage temperature

The NFT storage temperature was determined according to the previous method reported by Zhao et al. (Zhao et al., 2019) with some modifications. Initially, the temperature probes and recorder (HP34970A, Jing Chuang, China) were calibrated by 0 °C water and ice mixture (Jie et al., 2003). Then, ten apple fruit with similar size were selected randomly to determine the freezing temperature, the calibrated sensors were fully penetrated the middle of the pulp, the fruit (contain the sensors) were kept in a -20 °C freezer to obtain the biological freezing curves. The temperature values were recorded every 10 seconds. The biological freezing point and super-cooling point of apple fruit were determined based on the freezing curve.

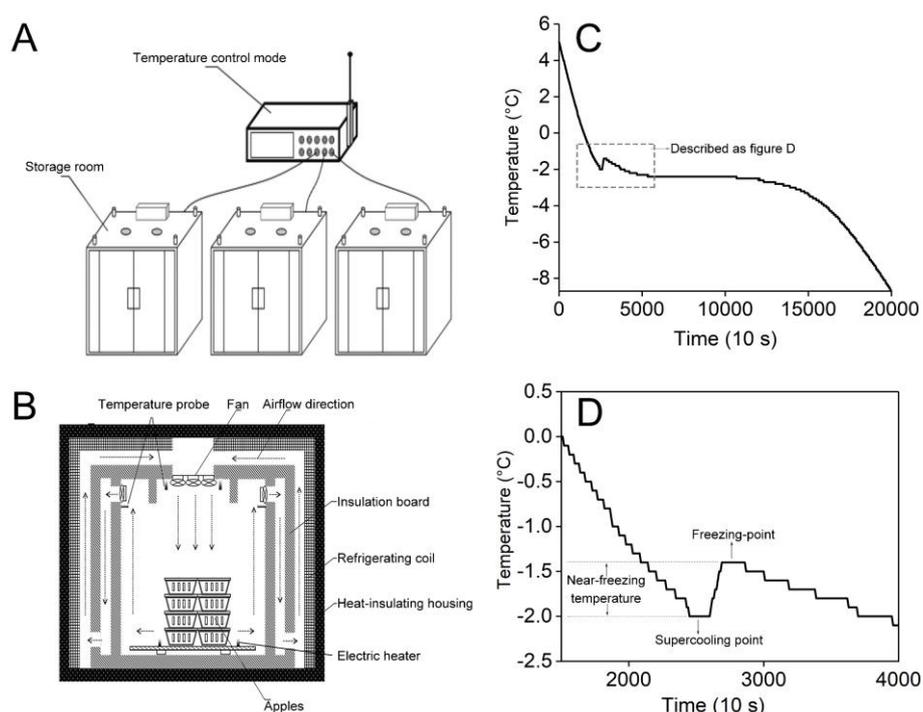


Figure S2 Schematic diagram of near-freezing temperature (NFT) storage equipment (A and B). The biological freezing curve of apple fruit (C) and the diagram of near-freezing temperature (D).

The freezing temperature curve of apple fruit was exhibited in **Figure S1C**. The curve displayed that the supercooling point and freezing point of fruit were -2.0 °C and -1.4 °C, respectively (**Figure S1D**). To avoid freezing damage, the storage temperature of apple fruit was controlled at -1.7 °C, with a ± 0.1 °C minimum temperature

fluctuation.

Table S1 The NFT storage temperatures applied over the storage period

Storage time (day)	Fruit SSC (%)	NFT storage temperature (°C)
0 ~ 50	13.7 ~ 13.4	-1.7 ± 0.1
50 ~ 100	13.4 ~ 12.8	-1.6 ± 0.1
100 ~ 150	12.8 ~ 11.8	-1.4 ± 0.1
150 ~ 200	11.8 ~ 11.2	-1.3 ± 0.1
200 ~ 250	11.2 ~ 10.4	-1.1 ± 0.1

To avoid freezing damage, the storage temperature of the NFT group was determined every 50 days. Ten fruit were randomly selected from each replicate for the NFT determination. The NFT storage temperature change upon fruit physical and chemical change was shown in **Table S1**, the results show that fruit NFT storage temperature increase upon storage time. A linear relationship was observed between soluble solids content and NFT storage (**Figure S3**).

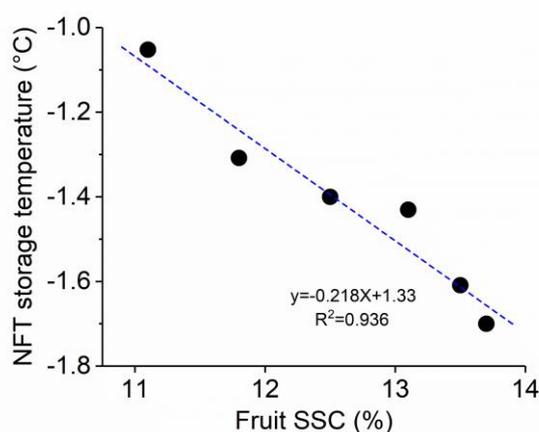


Figure S3. The correlation between soluble solids and NFT temperature

References

- Jie, W., Lite, L., & Yang, D. (2003). The correlation between freezing point and soluble solids of fruits. *Journal of Food Engineering*, 60(4), 481–484. [https://doi.org/10.1016/S0260-8774\(03\)00081-5](https://doi.org/10.1016/S0260-8774(03)00081-5)
- Zhao, H., Jiao, W., Cui, K., Fan, X., Shu, C., Zhang, W., Cao, J., & Jiang, W. (2019). Near-freezing temperature storage enhances chilling tolerance in nectarine fruit through its regulation of soluble sugars and energy metabolism. *Food Chemistry*, 289, 426–435. <https://doi.org/10.1016/j.foodchem.2019.03.088>