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Advantages of Liquid Nitrogen Quick Freezing Combine Gradient Slow Thawing for Quality Preserving of Blueberry

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Color Determines

CIELAB parameters (L*, a*, b*) were determined on the blueberry color using a colorimeter. (Ultra Scan VIS, Hunter Lab, CA, USA). L*, a*, b*represents luminosity value, redness or greenness value, and yellowness or blueness value respectively. The difference (ΔE) in color between the thawed and fresh samples was calculated by

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

where Li*, a* and b* indicates the color parameters of thawed blueberry samples, and L_0*, a_0* and b_0* refer to the color parameters of the fresh samples.

The result was the average of 12 tests.

Effects of Different Thawing Method on the Color Changes of Frozen Blueberry

As shown in Table 2, the color changes of thawed blueberries treated with various thawing processes are significant different. L* of all of them are decreased, which might because the white wax of blueberries surface is wiped with the water vapour phenomenon caused by thawing process. At the same time, PPO and POD are activated at some extent, and the cell partition may be destroyed with the freezing-thawing treatment lead to easier contact between the enzyme and the substrate, resulting in the oxidative polymerization and produce quinones in deep color. Gradient thawing has the best protective effect on color L* retention value of JD8 treatment is the highest and up to 93.79%. L* value of JD1 group is the lowest, decreased by 18%, compared with fresh blueberries, which may be because the microwaves promote enzymatic reactions of pigments. The a* and b* value of all thawing treatment shows increase tendency, indicating that the thawed blueberry tends to be blue. The increasement of a* and b* value of ultrasound group is the biggest, 100.93%, 25.13 respectively, and then is microwave group. This ultrasonic treatment can degrade the pigment and make the color dark [1]. ΔE^* represents overall changes of color. The ΔE^* change of JD1 group is the highest, while that of JD8 group is the lowest. The ΔE^* changes of each treatment group were similar to those of anthocyanin, but there were differences, mainly because the color of blueberry was determined by the combination of anthocyanin content and white waxy layer on the surface. In total, gradient thawing is the optimal way to thaw blueberry with great color, JD8 (−20～−5～4 °C) is the best treatment.

Table S1. Effects of different thawing method on the color changes of frozen blueberry.

Group	L*	a*	b*	ΔE*
JD1	23.96±0.37^{e}	1.87±0.13^{ab}	-3.12±0.17^{ab}	6.17±0.37^{a}
JD2	25.17±0.33^{de}	1.34±0.35c^{de}	-3.53±0.19^{ab}	5.21±0.28^{abc}
JD3	25.91±0.34^{cd}	2.02±0.11^{ab}	-3.45±0.18^{ab}	5.02±0.24^{bc}
JD4	26.27±0.34^{cd}	2.11±0.37^{a}	-2.94±0.18^{a}	4.73±0.25^{cd}
JD5	25.21±0.34^{de}	2.24±0.18^{a}	-2.91±0.34^{a}	5.92±0.36^{ab}
JD6	26.52±0.31^{bcd}	1.16±0.44^{de}	-3.37±0.21^{ab}	4.47±0.19^{cd}
JD7	26.62±0.36^{bc}	1.61±0.47^{bc}	-3.59±0.15^{ab}	4.38±0.23^{cd}
JD8	27.81±0.36^{b}	1.56±0.38^{bcd}	-3.87±0.19^{b}	3.69±0.16^{d}
Fresh	29.65±0.41^{a}	1.07±0.12^{e}	-3.90±0.15^{b}	/

Impacts of Different Thawing Method on Soluble Sugar and Vc Content of Frozen Blueberries

The impacts of different thawing method on soluble sugar and Vc content of frozen blueberries are significant (Figure 7). Both of them show a downward trend, and have similar change tendency: JD8 > JD7 > JD6 > JD1 > JD4 > JD5 > JD3 > JD2. This result is in line with the observation of strawberry founded by Oszmiański et al. [2]. The difference of soluble sugar is the combination of weight loss and pectin change, due to the water soluble sugar contains pectin and fiber etc. There is no markable difference of soluble sugar between gradient thawing group and fresh samples, the soluble sugar retention of JD8 group is reach to 98%. The loss retention of soluble sugar and Vc of room temperature thawing is 31.80%, 50.48% respectively, resulting in the worst thawing effect. Rizzolo et al. [3] found that there was a non-frozen phase in the pulp system, which led to a series of reactions such as diffusion control, causing oxidative degradation of some carbohydrate substances in the system. However, lower temperature conditions were conducive to slowing down the rate and occurrence of the diffusion control reaction, which had a better retention effect on the soluble sugar content.

Vc has strong reducibility and extremely poor thermal stability, and is prone to oxidative decomposition reaction. Its decomposition rate is easily affected by temperature, and low temperature can maintain the stability of Vc. Gradient thawing and low temperature thawing conditions are mild, with good treatment effect. The content of Vc in blueberry of microwave thawing was slightly lower than that in low-temperature thawing, which may cause some Vc loss due to microwave thermal effect. The thawing time of ultrasonic and static-water is faster, but the weight loss is serious. When the ultrasonic power increases, it also produces more mechanical vibration, which increases the degree of damage to cells.; and ultrasound has a certain degradation impact on [4].

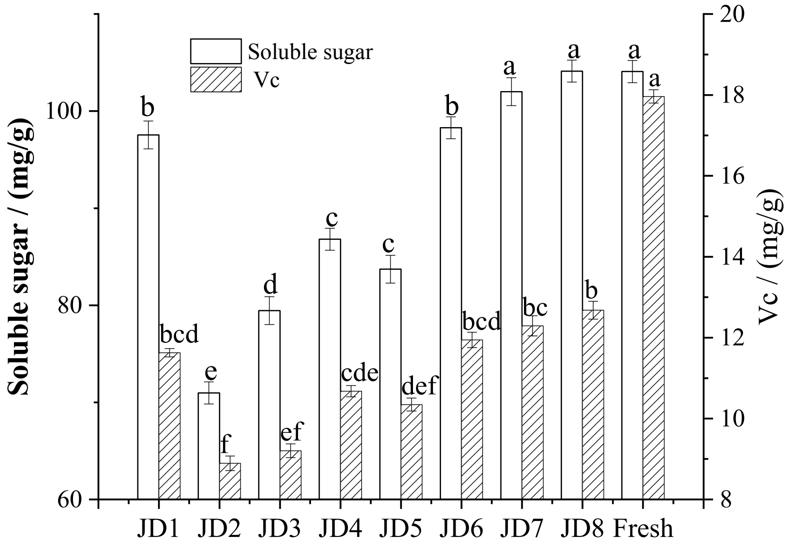

Figure S1. Effects of various thawing ways on the soluble sugar and Vc changes of frozen blueberries.

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