Light water loss delays mechanical injury of Actinidia arguta by Inhibiting cell wall metabolism

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Abstract

This study aimed to investigate the effect of light water loss on the mechanical injury of *Actinidia arguta* fruit by regulating cell wall metabolism. By comparing the effect of water loss on mechanical injury of *Actinidia argutaf*ruit after simulated transport vibration, the changes in sensory quality and cell wall metabolism of treated *Actinidia arguta* fruit during storage were measured, compared with non-water-loss simulated transport vibration as the control. Light water loss slowed the growth rate of pectin and cellulose and decreased the activities of polygalacturonase, pectin methylesterase, pectinlyase, cellulase, β-glucosidase, and β-galactosidase. Electron and transmission microscopy imaging show that light water loss helps maintain cell wall structure and slows down cell wall degradation. The results indicate that light water loss alleviates post-harvest mechanical injury in *Actinidia arguta* by regulating cell wall metabolism and inhibiting cell wall degradation, thereby contributing to the maintenance of redox homeostasis and cell structural integrity to maintain fruit quality.

1 Introduction

Actinidia arguta, also known as soft jujube, is a large deciduous vine in the kiwifruit family (Huang, 2020). Characterized by its smooth, hairless skin and relatively small size, weighing approximately 5 g–10 g, it is considerably smaller than commercially available kiwifruit. Its skin transitions from bright to light green or pink upon maturation (Sutherland et al., 2017), enclosing aromatic and flavorful berries that are either spherical or ellipsoidal in shape (Testolin et al., 2016). Notably, these fruits can be consumed unpeeled (Szpadzik et al., 2021). Cultivated extensively across regions of Northeast Asia, Northern Europe, North America, and other high-latitude countries (Tomasz et al., 2011; Latocha et al., 2017), *Actinidia arguta* has emerged as a commercially valuable berry, distinguished by its rich composition of multiple vitamins, amino acids, minerals, and bioactive substances (Baranowska et al., 2019). It serves as an excellent source of dietary fiber, contributes to digestive health, and plays a vital role in the prevention of metabolic syndrome, gastrointestinal tumors, and cardiovascular diseases (Monika et al., 2021). However, *Actinidia arguta's* climacteric nature results in limited post-harvest shelf life, with commercially ripe fruits rapidly softening within 5 d at 20 °C (Sutherland et al., 2017). The susceptibility of these fruits to mechanical injuries and decay during harvesting, post-harvest handling, and transportation remarkably diminishes their market value.

In a previous study, our laboratory demonstrated that post-harvest light water loss can prolong the storage longevity of *Actinidia arguta* while simultaneously decreasing its susceptibility to mechanical injury by accelerating fruit hardness. Analogous findings in citrus fruit indicate that light water loss enhances stress resistance, thereby reducing losses attributed to mechanical injuries and diseases (Cao et al., 2019). Fruit softening is characterized by the degradation of cell wall structure, which includes a range of polysaccharide components, such as pectin and cellulose (Fan et al., 2019), which play a crucial role in maintaining structural integrity and enhancing intercellular adhesion. Cell wall degradation affects the brittleness and hardness of fruit during ripening and aging (Zhai et al., 2018; He

et al., 2020) and accelerates the degradation of PG, PME, PL, cellulase, and β-glu enzymes. (Aubert et al., 2014; Lin et al., 2020).

Despite the potential benefits of light water loss in prolonging storage life and mitigating post-harvest mechanical damage, research in this domain remains scarce. Therefore, it aims to elucidate the impact of light water loss on the cell wall metabolism of *Actinidia arguta* under simulated post-harvest mechanical stress, providing a theoretical basis and reference value for the development of new storage and transport preservation technologies for this fruit.

2 Materials and methods

2.1 Fruit material and treatment

2.1.1 Fruit material

The study utilized "Longcheng II" *Actinidia arguta*, harvested from a well-managed orchard in Kuandian County, Dandong City, Liaoning Province. Post-harvest, the fruits were immediately transported to laboratory in a foam box with ice packs. Only fruits of uniform size and maturity, free from any diseases, pests, or physical damage, were selected for the experiments.

2.1.2 Water-loss treatment

A total of 240 *Actinidia arguta* fruits, free from pest or disease damage, were selected. These were evenly divided into two groups: the control group was stored in a sealed bag, whereas the other group was placed on a test bench covered with gauze to undergo "water-loss" treatment. A fan was activated to facilitate the process, with laboratory conditions maintained at approximately 25 °C and humidity between 72% and 78%. The treatment duration was determined based on achieving a 4% water-loss rate within 3 h, a criterion established from preliminary experiments and references (Jiang et al., 2013).

2.1.3 Simulated transport vibration treatment

Both dried and untreated fruits were further divided into four groups, each containing 60 fruits, and placed in plastic foam boxes measuring 280 mm in length, 220 mm in width, and 120 mm in height. They were subjected to vibration using a simulated transport shaker to replicate transport conditions. Research has shown that the vibration frequency distribution of vehicles during transportation ranges between 2 and 5 Hz. As such, we employed a vibration frequency of 120 r/min (2 Hz) (Jarimopas et al., 2010). Considering studies suggesting that strawberries experience increased damage and electrical conductivity (Chaiwong et al., 2015) at vibration levels of 5 Hz for 150 s, vibration treatments of 5 and 10 min were selected. The treatment method is shown in Table 1. After the treatment, fruits were stored at a simulated room temperature of 25 °C ± 1 °C for 10 d, with phenotypic changes observed daily. Ten samples were selected from each group. The pulp of Actinidia arguta was rapidly frozen using liquid nitrogen and preserved at -80 °C for later analysis of quality and physiological parameters.

2.2 Sensory quality

Appearance quality was assessed every 2 d using a photobox to capture and document changes. Fruit hardness was determined according to Yang et al. (2019), employing a texture analyzer on the equatorial part of the fruit at two distinct points. The decay rate was calculated using a method slightly modified from Zhang et al. (2022), categorizing fruits based on visible disease spots, swelling, and skin color changes into grades 0–4: Rot rate (%) =Σ rot level × number of samples of this grade/highest grade × total number of samples × 100%.

2.3 Microstructural changes

2.3.1 Scanning electron microscopy (SEM)

For each treatment, fruit samples were taken, and the pulp was excised using a sterile scalpel to produce sections not exceeding 3 mm^2. These sections were then fixed and stored at 4 °C before being dried using a vacuum freeze-dryer. Subsequently, using an ion-sputtering coater, the dry samples were labeled using a scanning electron microscope.

2.3.2 Transmission electron microscope (TEM)

Adapting the method by Taylor et al. (1998), *Actinidia arguta* fruits were divided into cuboids (1 mm × 1 mm × 3 mm) and rinsed in a phosphate buffer containing glutaraldehyde as a fixative, a process repeated three times. Following gradient elution and dehydration, the samples were embedded, sectioned at room temperature, and then analyzed using transmission electron microscopy.

2.4 Cell wall components

The quantification of both native and soluble pectin followed the methodology proposed by Tang et al. (2020), utilizing carbazole colorimetry for pectin content determination. The analysis of cellulose and alcohol-insoluble substances (AIS) within the fruit cell walls was conducted using specific assay kits, with results reported in mg g^{-1}.

2.5 Pectin-degrading enzyme activity

PG activity was assessed following Zheng et al. (2019), with activity expressed as the conversion rate of polygalacturonic acid to galacturonic acid at 37 °C, expressed in μg $h{\cdot}g^{-1}$. PME activity determination was guided by the method of Ren et al. (2020), using a 10 g L^{-1} pectin solution as the substrate, and was expressed as the mass of pectin methyl ester released by PME at 37 °C per h per g of sample (U g^{-1}). Pectin lyase (PL) activity was measured using a kit, with results also expressed as U g^{-1}.

2.6 Cellulose-degrading enzyme activity

Cellulase activity was determined by following the approach of Cao et al. (2013) with some modifications. It involved quantifying the production of reducing sugars catalyzed by cellulase using a 10 g L^{-1} sodium carboxymethyl cellulose (CMC) solution as the substrate. The corresponding glucose content was determined from a standard curve based on the difference in absorbance between the experimental and control groups. Cellulase activity was expressed as the mass of CMC catalytically hydrolyzed to reducing sugar at 37 °C per g of sample per h (μg $h \cdot g^{-1}$). β-Gal activity was determined with a slight modification of the method described by Yz et al. (2019). Using p-nitrobenzene-β-D-galactoside pyranopyranoside as a substrate, 1 nmol p-nitrophenol production per g of tissue per h was defined as an enzyme activity unit. To determine β-Glu activity, we referred to the method described by Ji et al. (2021).

2.7 Data analysis

Each experimental procedure was replicated three times. Excel was used for data processing, whereas Duncan's multiple range test ($P < 0.05$) in SPSS 24.0 was used for statistical analysis. Pearson's correlation test was applied for correlation assessments, and Origin 2021 software facilitated graphical representations of the data.

3 Results

3.1 Alterations in sensory appearance quality

The effect of water loss on the sensory appearance of post-harvest *Actinidia arguta* is shown in Fig. 1. During the initial storage phase (2 d–4 d), no significant differences were observed in appearance across treatment groups. However, in the middle storage stage, $Control_1$ and $Control_2$ in the control group exhibited minor browning, which progressively intensified as storage duration increased, culminating in a complete loss of commercial value by day 10. Conversely, the appearance quality of *Actinidia arguta* in the treatment groups, S_1 and S_2, remained superior to that of $Control_1$ and $Control_2$ on day 10.

3.2 Changes in skin hardness and decay rate

Fig. 2A shows the effect of water-loss treatment on the hardness of the skin during post-harvest storage, revealing a gradual decrease in hardness and subsequent softening over time. Fig. 2B shows that the fruit decay rate increased gradually with prolonged storage. After 2 d, *Actinidia arguta* in S_1 of the treatment group did not rot, whereas initial signs of rot were evident in $Control_1$, $Control_2$, and S_2. By day ten, the decay rates for $Control_1$ and $Control_2$ were 30% and 34%, respectively, in contrast to 20% and 25% for S1 and S2 within the treatment groups. These findings suggest that light water-loss treatment can effectively delay the escalation of decay rates in *Actinidia arguta*.

3.3 Microstructure changes

3.3.1 SEM

SEM imagery reveals the changes in fruit structure and morphology at 0, 6, and 10 d under control and light water-loss conditions (Fig. 3). Initially, on day zero, the fruit displayed a smooth, flat surface with normal cellular morphology and structure, a clear distribution, and abundant starch grains. By the sixth day, starch degradation commenced, as evidenced by the digestion and fragmentation of starch particles, leading to a decrease in hardness. The texture and tissue outline in the treatment group were clear and densely distributed, whereas the structure in the control group was loose and damaged to a certain extent. The cell structure collapsed and softened considerably. After 10 d of storage, the starch granules in the treatment group disappeared, resulting in a loose, porous structure with large voids and advanced softening. Meanwhile, the cells in the control group were destroyed, deformed, and unable to carry out metabolic activities. These observations indicate that light water loss can mitigate cell wall degradation rates, thus delaying the senescence and softening of *Actinidia arguta* fruit.

3.3.2 TEM

TEM observations of *Actinidia arguta* throughout storage periods are shown in Fig. 4. Initially, the cell walls and plasma membranes of freshly harvested fruit were intact, exhibiting a close association between the cell membrane and cell wall. Starch granules were observed adjacent to the cell walls, and trijunction regions between cells were well-defined, complete with mitochondria. After 6 d of storage, starch granules began to degrade, and the trijunction areas between cells began to liquefy, leading to an expansion of the voids. In the treatment group, the cell wall and cell membrane remained intact, with organelles intact and a reduction in membrane permeability noted. Conversely, the cell wall of the control group was degraded, resulting in a loose and incomplete structure with irregular edges and plasmic wall separation. At later storage stages, cells in the treatment group exhibited severe cavitation, with a marked loss of structural integrity and organelles. The control group, however, experienced the disappearance of intercellular layers and filaments, along with considerable cell wall damage. These TEM findings suggest that light water loss can alleviate mechanical damage and maintain fruit quality.

3.4 Changes in original pectin and soluble pectin

The effect of water-loss treatment on the pectin content of *Actinidia arguta* is shown in Fig. 5. As storage duration increased, coinciding with fruit maturation, a decline in native pectin levels was observed, along with a gradual shift from native to soluble pectin, characterized by decreasing native pectin and increasing soluble pectin levels. light dehydration effectively slowed the conversion to soluble pectin within *Actinidia arguta*. During the storage period, a downtrend in native pectin was noted, with the S_1 and S_2 groups displaying concentrations of 0.45% and 0.33% on the 4^{th} day, respectively, representing 1.13 and 1.06 times higher than that of the control group at the same period, respectively. Initially, from 0 to 2 d, soluble pectin levels between the treatment and control groups exhibited no remarkable divergence. However, water-loss treatment significantly inhibited the increase in soluble pectin content in *Actinidia arguta*, with the S_1 group in the dehydration treatment exhibiting 18.1% and 22.3% soluble pectin on days 4 and 6, respectively, marking reductions of 21.3% and 12% compared to Control1 of the control group. Meanwhile, the soluble pectin levels of S_2 in the water-loss treatment group were 31.8%

and 44.4%, respectively, against 36.7% and 49.3% in $Control_2$ of the control group. Therefore, light dehydration treatment notably impedes pectin conversion and delays senescence in *Actinidia arguta*.

3.5 Alterations in cellulose and AIS

Fig. 6 shows the effects of water loss on cellulose and AIS levels in *Actinidia arguta*. During storage, an initial increase followed by a decrease in cellulose was observed. Compared with the control group, the increase in cellulose content in the water-loss treatment group was significantly inhibited. By the fourth day of storage, the cellulose levels in S_1 and S_2 in the dehydrated group were 367.91 and 481.4 mg g^{-1}, respectively, representing reductions of 10.2% and 26.1% relative to $Control_1$ and $Control_2$, respectively. AIS, a critical cell wall component, mirrors the cell wall degradation and fruit softening processes. A declining trend in AIS was noted during storage; nevertheless, the levels in the treatment group consistently exceeded those in the control group, indicating that water loss delayed the decline in AIS content. These results indicate that light water-loss treatment curtails the degradation of cell wall components in *Actinidia arguta* fruits.

3.6 Variations in pectin-degrading enzyme activity

PG activity, which catalyzes polygalacturonic acid to galacturonic acid, thereby destabilizing cell components and facilitating fruit softening (Win et al., 2021), is shown in Fig. 7A. The PG activity in *Actinidia arguta* initially increased, then decreased over the storage duration. Notably, PG activity in the dehydration-treated samples remained lower than that in the control group throughout the storage period. The peak PG activity in the control group was observed on the sixth day, reaching levels of 1.05 and 1.10 times higher than those in the S_1 and S_2 groups, respectively. These results suggest that light water-loss treatment significantly attenuated PG activity in *Actinidia arguta* ($P < 0.05$).

As shown in Fig. 7B, PME activity in *Actinidia arguta* increased with prolonged storage. After 6 d of storage, the PME activities of S_1 and S_2 in the treatment group were 107.4 and 115.2 U g^{-1}, respectively, which were 4% and 5% lower than those observed in $Control_1$ and $Control_2$, respectively. Light treatment significantly inhibited the increase in PME activity ($P < 0.05$), indicating that light water-loss treatment can delay the degradation of PME by reducing the PME activity of *Actinidia arguta*.

Fig. 7C shows the effect of light water-loss treatment on PL activity in *Actinidia arguta*. The PL activity exhibited an initial increase followed by a decrease. Furthermore, PL activity in the treatment samples was lower than that in the control group. The PL enzyme activities of $Control_1$ and $Control_2$ in the control group and S_1 and S_2 in the treatment group peaked on the sixth day of storage. The enzyme activities of S_1 and S_2 in the treatment group were 111.59 and 148.91 U g^{-1} lower than those in the control group by 5.2% and 6.8%, respectively. These results affirm that light water-loss treatment significantly reduces PL enzyme activity in *Actinidia arguta* ($P < 0.05$).

3.7 Changes in vitamin-degrading enzyme activity

Cellulase can promote cellulose degradation and regulate fruit ripening and senescence. The effect of light water-loss treatment on the cellulase activity of *Actinidia arguta* is shown in Fig. 8A. The cellulase activity of the control group was significantly higher than that of the treatment group ($P < 0.05$). On the fourth day of storage, the cellulase activities of $Control_1$ and $Control_2$ in the control group were 433.74 and 481.4 mg g^{-1}, respectively, which were 1.1 and 1.45 times more than those of S_1 and S_2 in the treatment group, respectively.

With the extension of storage time, the β-Gul activity of *Actinidia arguta* increased initially and then decreased, as shown in Fig. 8B. The β-Gul activity of *Actinidia arguta* samples after water-loss treatment was lower than that in the control group. β-Gul activities of S_1 and S_2 in the treatment group were 502.5 and 580.8 U g^{-1}, which were 11.2% and 7.1% lower than those of $Control_1$ and $Control_2$ in the control group, respectively.

The effects of water-loss treatment on the β-Gal activity of *Actinidia arguta* are shown in Fig. 8C. With storage time extensions, β-Gal activity initially increased and then decreased. Enzymatic activity within the treatment group was lower than that in the control group. Specifically, β-Gal activity reached a maximum on the fourth day of storage for both $Control_2$ in the control group and S_2 in the treatment group. The β-Gal activity for S_2 in the treatment group was significantly lower than that of $Control_2$ in the control group, with enzyme activities of 2832 and 2566.3 U g^{-1}, respectively. On the eighth day, peak β-Gal activity of $Control_1$ in the control group and S_1 in the treatment group were 2712 and 2154.9 U g^{-1}, respectively, with $Control_1$ in the control group significantly surpassing that of S_1 in the treatment group. These results indicate that light water loss during storage inhibits the activity of the cellulose-degrading enzyme.

3.8 Correlation analysis

The correlation analysis results of fruit appearance quality, cell wall components, and cell wall-related enzyme activities are shown in Table 2. Fruit hardness was positively correlated with original pectin and AIS content and negatively correlated with rot rate, soluble pectin, pectinase (PG, PME, and PL), cellulase, and β-Gul enzyme activities. The decay rate was positively correlated with the activities of soluble pectin, pectinase (PG, PME, PL), cellulase, and β-Gul and negatively correlated with the contents of original pectin and AIS. Original pectin was positively correlated with AIS content and negatively correlated with soluble pectin, pectinase (PG, PME, and PL), cellulase, and β-Gul enzyme activities. The activities of soluble pectin pectinase (PG, PME, and PL), cellulase, and β-Gul were positively correlated with AIS and negatively correlated with AIS. There was a significant positive correlation between cellulose and β-Gal enzyme activity. AIS was significantly negatively correlated with pectinase (PG, PME, and PL), cellulase, β-Gul, and β-Gal activity. PG was positively correlated with PME, PL, cellulase, and β-Gal enzyme activities. PME was positively correlated with PL, cellulase, and β-Gul enzyme activities. PL was

positively correlated with cellulase and β-Gul enzyme activities. There was a significant positive correlation between cellulase and β-Gul activity.

4 Discussion

Post-harvest, fruits and vegetables undergo various physiological activities to maintain normal metabolic functions. It is widely recognized that fruit ripening and softening entail complex processes characterized by cell wall degradation and alterations in cellular inclusions.

Light water loss may be caused by promoting a decrease in hardness in the early stages, making the fruit resistant to stress, stimulating internal protective mechanisms, and enhancing adaptability, thereby enhancing the cell wall's tolerance to mechanical damage during transportation and storage of *Actinidia arguta*. In this study, 4% water-loss treatment maintained cell wall components, inhibited pectinase and cellulase activities, reduced the effect of mechanical injury on the cell wall through light water loss, and delayed the aging of *Actinidia arguta*.

The cell wall is mainly composed of pectin and cellulose, and in immature fruit, pectin substances are combined with cellulose in the form of protopectin. The original pectin is a type of non-water-soluble substance that makes the fruit appear solid, brittle, and hard. With maturation, pectin detaches from cellulose, transforming into water-soluble pectin, which leads to the softening and relaxation of fruit tissue and a reduction in hardness. Cellulose, a crucial dietary fiber, remarkably influences the quality and storage of fruits and vegetables and is essential for their mechanical damage resistance, disease prevention, and pest resistance. In this experiment, the analysis of cell wall degradation in *Actinidia arguta* fruit revealed a decline in native pectin and AIS levels, an increase in soluble pectin, and an initial rise followed by a decrease in cellulose content. However, the slightly dehydrated *Actinidia arguta* fruit contained higher contents of original pectin and AIS and lower contents of soluble pectin and cellulose than those in the control group, aligning with findings from Jiang et al. (2013) and Zeng (2014).

During fruit ripening, enzymatic actions lead to cell wall lysis and transformation, resulting in cell wall thinning, loosening of cells, and subsequent softening (Chen et al., 2020; Wantat et al., 2021). PG, cellulase, and β-Gal are the main cell wall degrading enzymes, which play different roles in different stages of fruit softening (Brummell et al., 2006). This study has demonstrated that water-loss treatment decelerates the degradation rate of cell wall components, inhibits related enzyme activities, maintains cell firmness, and enhances the fresh-keeping effect.

Pectinase encompasses a group of complex enzymes responsible for the decomposition of pectin, primarily including PG, PME, and PL. PG is one of the pectin-degrading enzymes and is considered crucial for controlling the increase in water-soluble pectin content and facilitating fruit softening. PG activity, pivotal for pectin degradation, varies with the ripening stages, intensifying during the mid-phase of ripening. PME plays a vital role by demethylating pectin, thereby catalyzing its conversion to pectic acid and facilitating PG's action in fruit softening. PL is a pectin enzyme that lyses pectin polymers by trans-elimination. In this study, with fruit ripening and senescence, the activity of pectinase (PG and PL)

increased first and then decreased, whereas the activity of PME increased consistently. The results indicated that light water-loss treatment inhibited the increase in pectinase activity, thus slowing down the degradation of pectin and delaying the softening process of fruit. This is consistent with the results of Wang et al. (2022).

Cellulose undergoes gradual hydrolysis to yield glucose. β-glucosidase, a vital cellulase component, influences cell wall dynamics during plant cell growth and development. The β-Gul enzyme, besides its role in cellulose glycosylation, is intricately linked to the metabolism of various substances in fruit and vegetables. β-galactosidase contributes to cell wall disintegration and catalyzes fruit softening. This study found that during the storage of *Actinidia arguta* fruit, cellulase activity, along with β-Gul and β-Gal activities, initially increased first and then decreased, with light water loss mitigating the rise in cellulase activity (Xiong et al., 2023). This result was also confirmed by the study. These findings suggest that light water loss hampers the senescence of the fruit cell wall during storage, preserving cell wall integrity and maintaining the cellular microenvironment and normal physiological metabolism.

5. Conclusions

light water loss can alleviate the effects of post-harvest mechanical injury on the storage quality of *Actinidia arguta* by facilitating a reduction in hardness and, thus, decreasing susceptibility to mechanical stress. Furthermore, it conserves cell wall integrity, prolongs the fruit's aging process, and sustains marketability.

Declarations

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Contribution statement

XinyuYu: Investigation, Data curation, Formal analysis, Writing - original draft.

WANG Qing-xuan,WANG Jin-yan: Conceptualization, Supervision, Visualization.

Qian Zhou:Conceptualization, Resources.WEI Bao-dong: Investigation, Conceptualization.

CHENG Shunchang□SUN Yang: Project administration, Funding acquisition, Writing - review & editing.

Conflict of interest

The authors declare no conflicts of interest.

Data statement

All data included in this study are available upon request from the corresponding author.

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Table

Table 1 Comparison table of treatment methods

Processing code	$Control_1$	$Control_2$	S_1	S_2
Treatment method	Without losing water, The simulated vibration time is 5 min	Without losing water, The simulated vibration time is 10 min	Water loss of 4%, The simulated vibration time is 5 min	Water loss of 4%, The simulated vibration time is 10 min

Figures

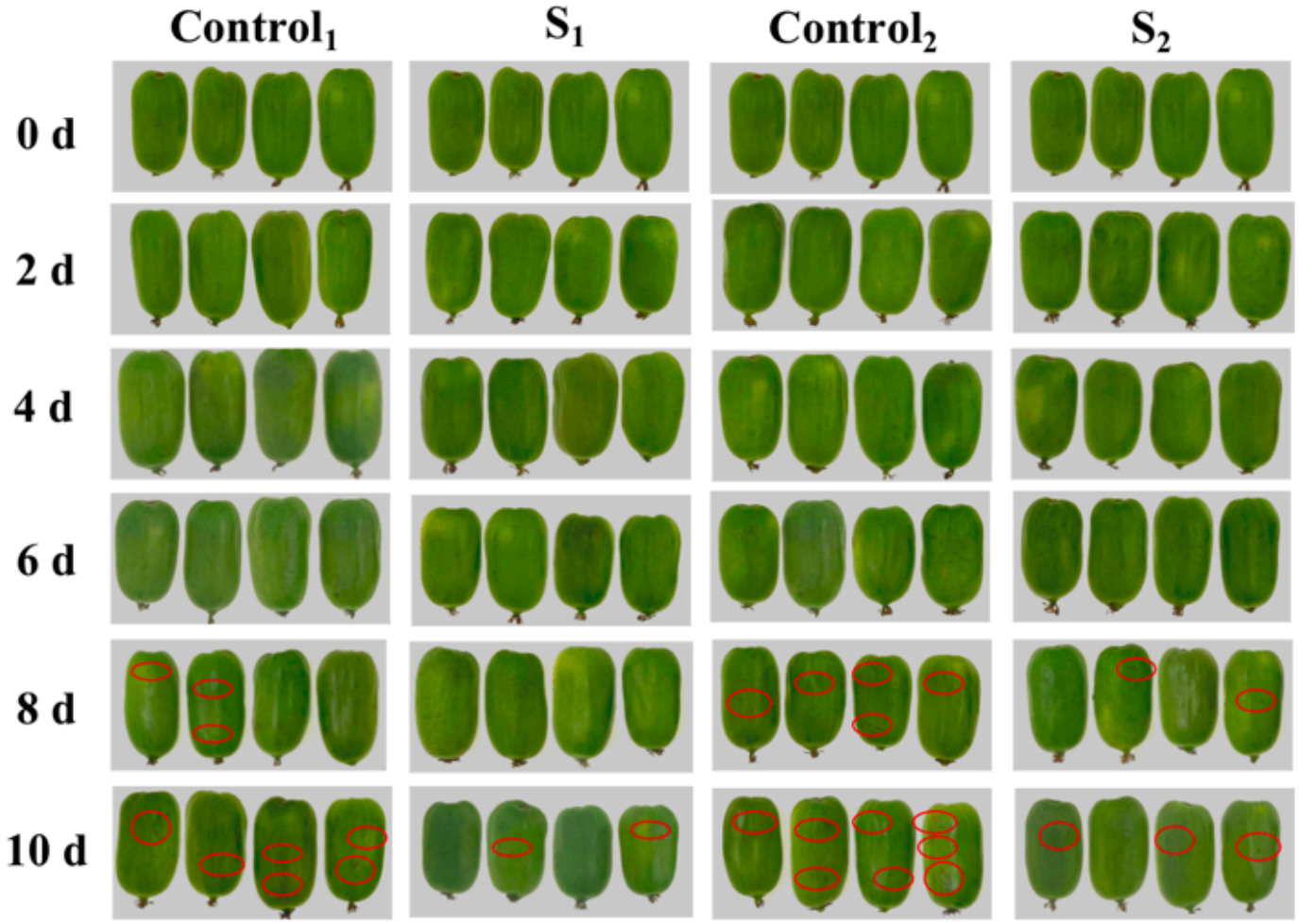

Figure 1

Effect of 0d-10d water loss treatment on appearance quality of Actinidia arguta.

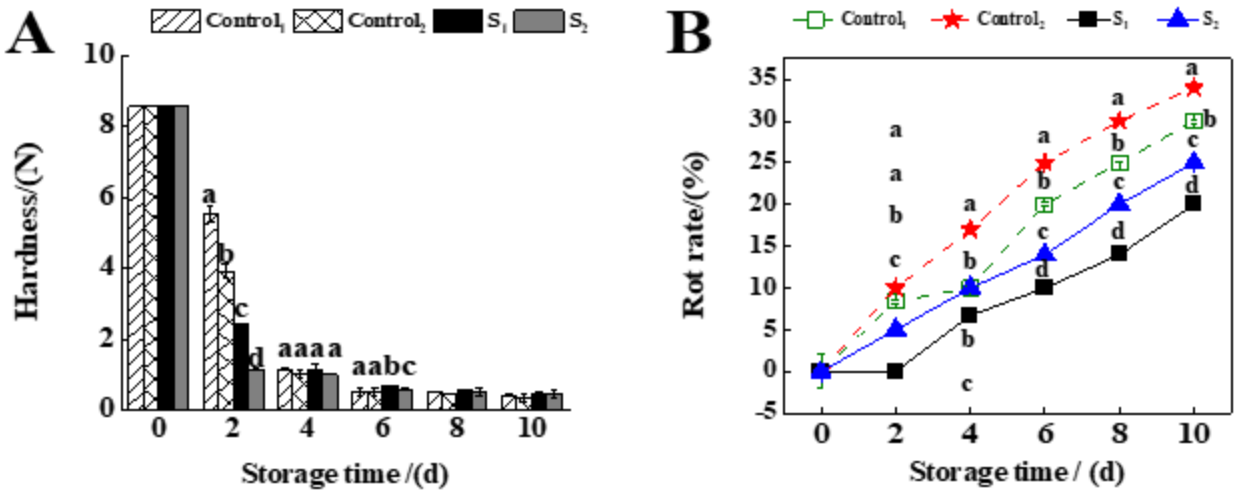

Figure 2

Effect of water loss treatment on hardness (A) and decay rate (B) of Actinidia arguta.The mean values were compared using Duncan’s multiple range test at a significance of $P < 0.05$.

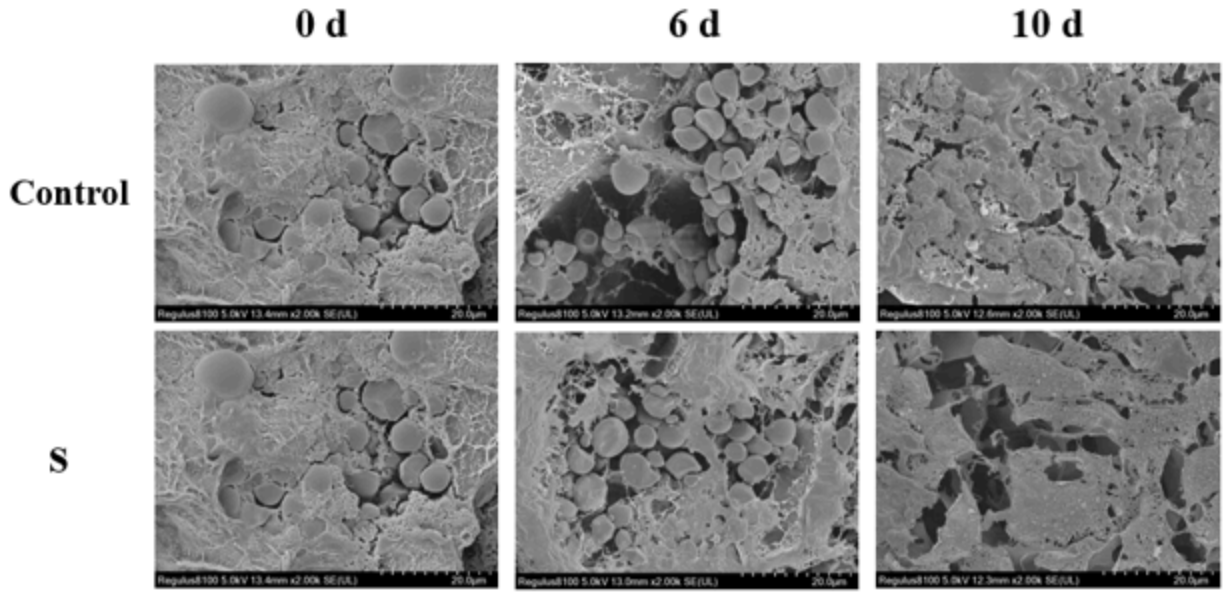

Figure 3

Morphological observation and comparison of postharvest Actinidia arguta by water loss treatment under SEM in 0d、6d and 10d control group and treatment group S1.

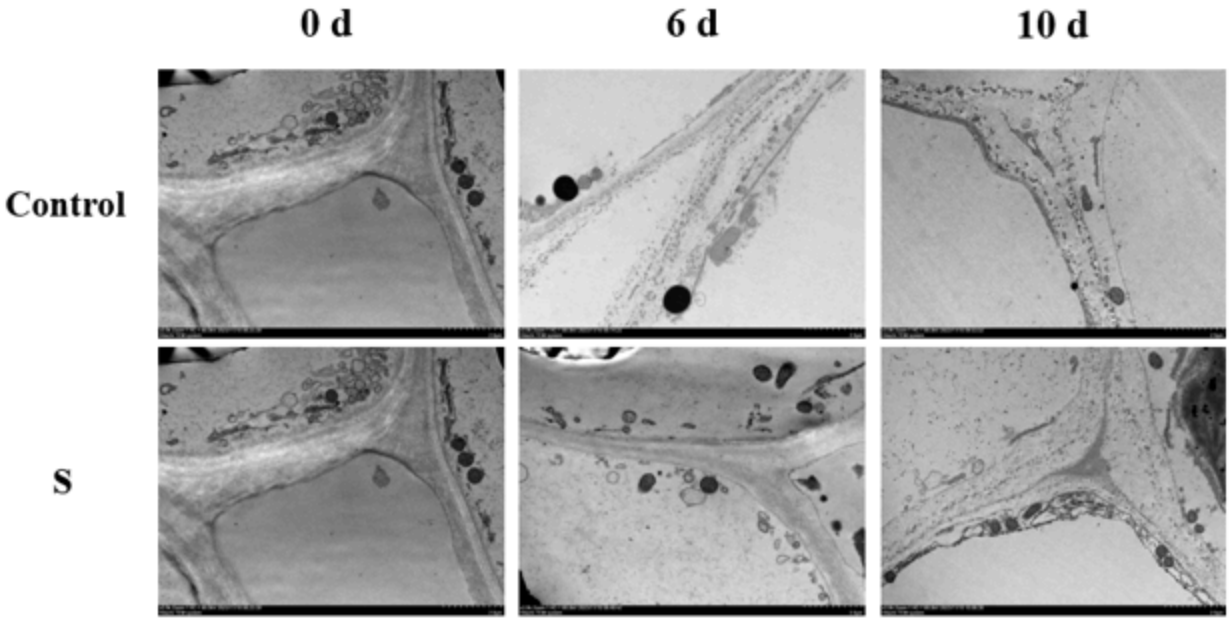

Figure 4

Observation and comparison of postharvest morphology of Actinidia arguta fruit under TEM after water loss treatment in 0d、6d and 10d control group and treatment group S1.

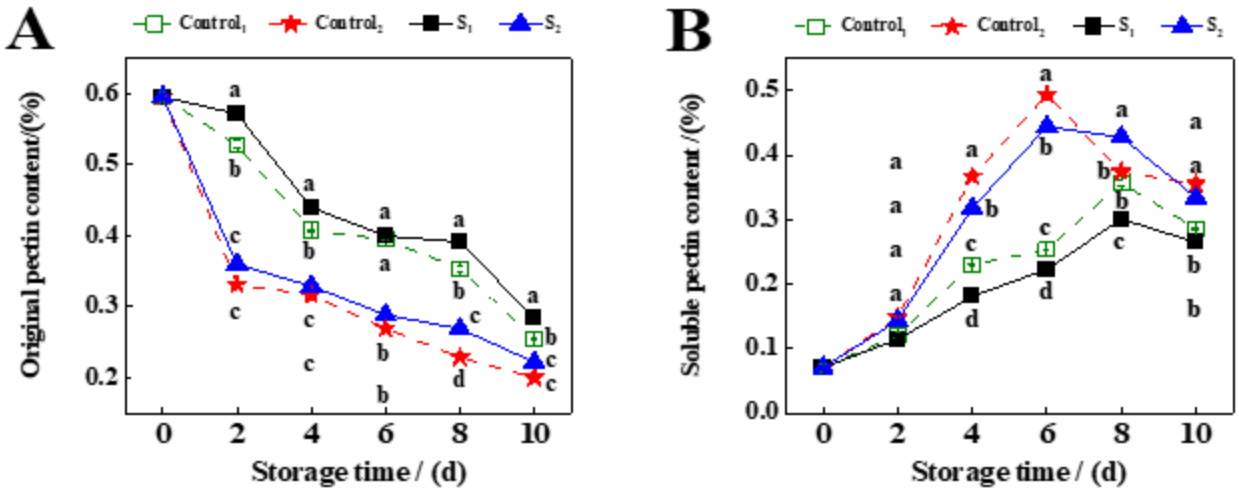

Figure 5

Effect of water loss treatment on raw pectin and soluble pectin of Actinidia arguta.The mean values were compared using Duncan's multiple range test at a significance of $P < 0.05$.

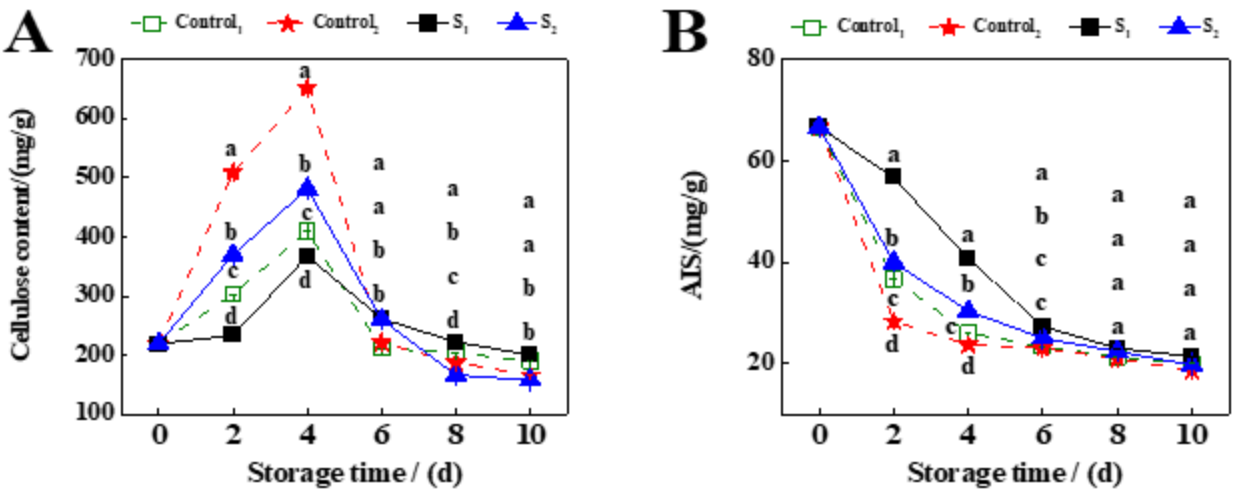

Figure 6

Effect of water loss treatment on cellulose and AIS in Actinidia arguta.The mean values were compared using Duncan's multiple range test at a significance of $P < 0.05$.

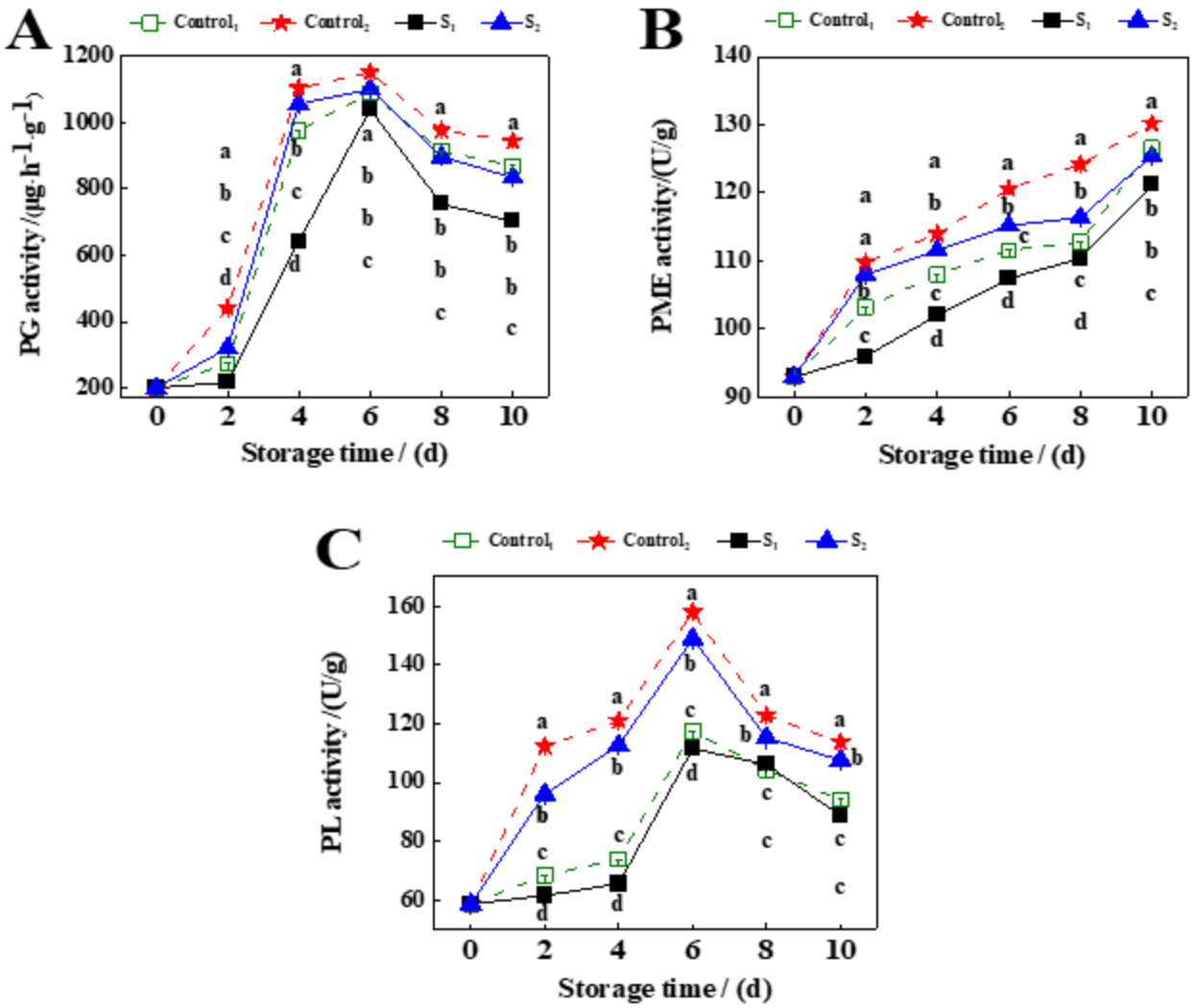

Figure 7

Effects of water loss treatment on the activities of PG (A), PME (B) and PL (C) enzymes in Actinidia arguta.The mean values were compared using Duncan's multiple range test at a significance of $P < 0.05$.

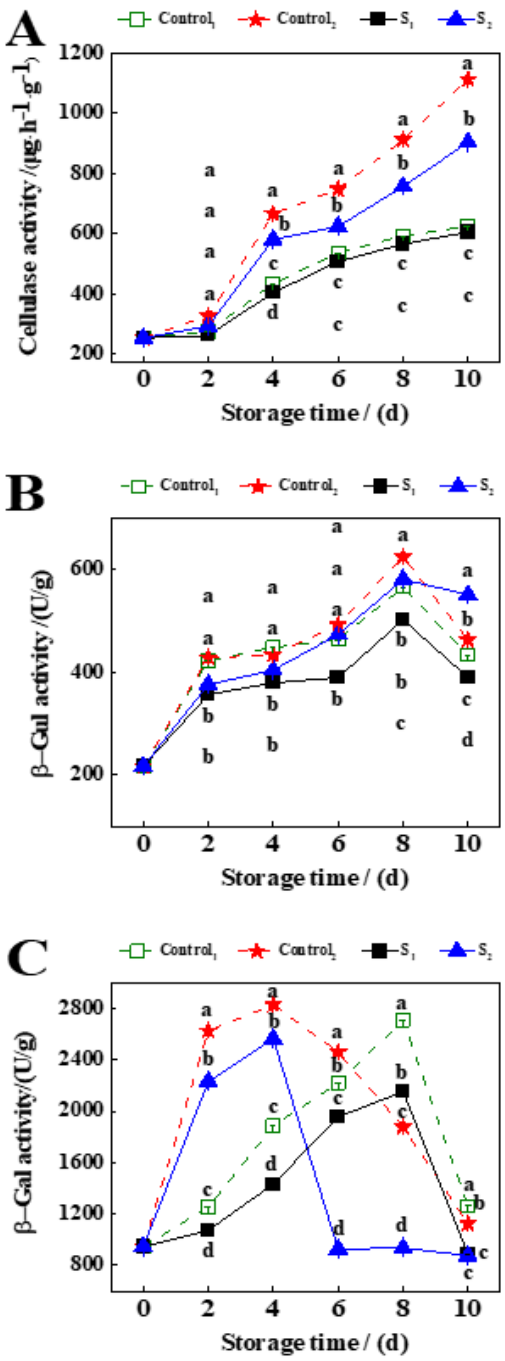

Figure 8

Effects of water loss treatment on CX (A), β-Gul (B) and β-Gal (C) enzyme activities in Actinidia arguta.The mean values were compared using Duncan's multiple range test at a significance of $P < 0.05$.

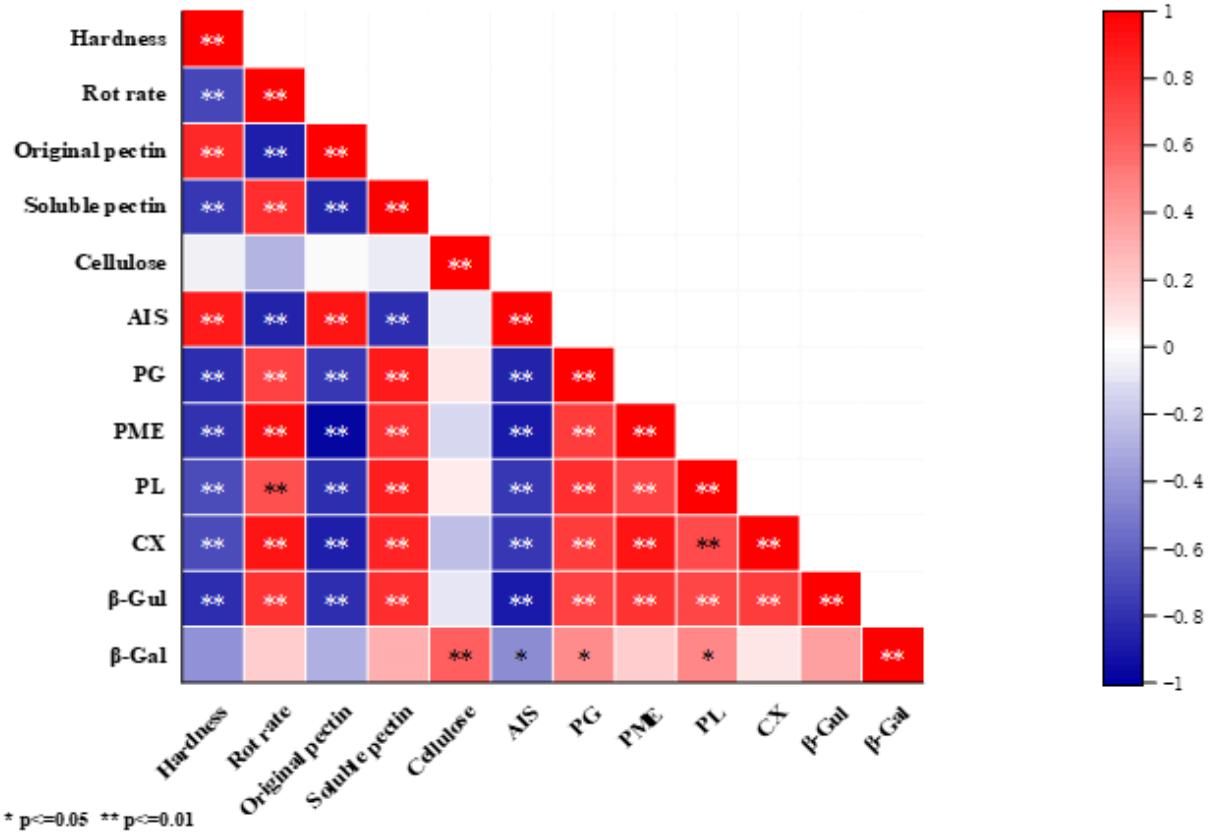

Figure 9

Pearson's Correlation analysis.Single asterisks (*) represent significant correlations at P < 0.05, and double asterisks (**) represent significant correlations at P < 0.01. Shades of red represent various

degrees of positive correlations and shades of blue indicate various degrees of negative correlations as indicated in the scale bar on the right of the heat map.

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