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Textural Monitoring of Ripening Process of Hayward Kiwi Stored with Apple and Quince

Mehmet Murat KARAOĞLU[1*], Aslıhan HANOĞLU[1]

Highlights:

- Storage process with apple is a quite good method in the natural and fast ripening process of kiwi.
- Storage process with quince can be preferred for demands in which the current ripeness level of kiwi is desired to be kept.
- Storage process at room temperature and increase in storage time led to decreases in textural parameters.

ABSTRACT:
The possibility of using apple and quince in the natural ripening process of climacteric kiwi fruit, which takes a long time to ripen due to a low ethylene release level after harvest, was investigated. Kiwi samples were stored separately, accompanied by apple and quince at different storage temperatures (4ºC and 20ºC) and periods (15, 30 and 45 days) and examined in terms of textural properties. It was determined that storage process accompanied by apple decreased firmness, chewiness and gumminess values of kiwi samples. In contrast, the storage process accompanied by quince did not exhibit a significant decreasing effect on these values. Storage process at room temperature and increase in storage time led to decreases in textural parameters in general. The penetration force (137.25-1722.33 g) and penetration work values (352.40-6453.45 g.s) of samples mainly changed depending on firmness. A similar tendency was also observed in relaxation time (8.40-124.83 s), maximum force (1.05-77.50 N) and minimum force values (0.41-50.07 N). As a result, it has been determined that storage process accompanied by apple is a quite good option in the natural, fast and accessible ripening process of kiwi and provides approximately 28% general reduction in fruit firmness. Storage treatment accompanied by quince can be recommended for demands in which the current ripeness level of kiwi is desired to be kept. In addition, it has been concluded that in cases in which rapid ripening is required, the choosing of storage process at room conditions will be more suitable due to its ripening-promoting effect.

Keywords:

- Kiwi
- Natural ripening
- Ethylene
- Textural properties
- Apple
- Quince

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INTRODUCTION

A prevalent method of fruit classification categorizes them based on their capacity to produce and respond to ethylene during the ripening process. In this regard, they are classified into two main groups: climacteric and non-climacteric fruits (Chen et al., 2018). Climacteric fruits continue to ripen by entering a climacteric phase, which is a critical process for ripening of climacteric fruits and characterized by increased respiration rate and ethylene release, after harvest. Therefore, they are harvested green and hard, to be ripened with ethylene gas near consumption to minimize losses. In contrast, non-climacteric fruits do not show postharvest ripening, there is no characteristic increase in respiration rate and ethylene production is at very low levels (Abhishek et al., 2016).

Kiwi (*Actinidia* spp.) is a fruit with typical climacteric characteristics (Lim et al., 2017). Kiwi, a deciduous, perennial, temperate climate fruit belonging to the Actinidiaceae family, has more than 70 species (Tilahun et al., 2020). One of the most well-known varieties is Hayward kiwi (*Actinidia deliciosa*), which can be grown on various conditions (Park et al., 2013). Kiwi, which is one of the popular fruits today, has biologically active components that are significantly beneficial to human health, such as polyphenols, carotenoids and ascorbic acid, dietary fibers and minerals etc. and its consumption has increased considerably recently due to its high nutritive value and medical benefits (Park et al., 2013; Vasile Scăețeanu et al., 2019).

On commercial terms, kiwi fruits are harvested in a physiologically mature, yet unripe phase and kept in storage environment with low temperature (0ºC) (Tilahun et al., 2020). At this stage, the firmness of kiwi, which is the main parameter determining the ripening degree, is quite high and ethylene production is at minimum level, implying that it takes long to ripen (Lim et al., 2017), during which uneven ripening, weight loss and drying may occur (Abhishek et al., 2016). Both these risks and consumers' desire to buy kiwi at a ripeness that is ready to be eaten direct the food industry to apply artificial ripening procedures such as exogenous ethylene treatment (Tilahun et al., 2020). It has long been known that ethylene is a trigger and regulator of ripening process in the climacteric fruits (Yang and Lim, 2017). Ripening is a complex process, in which various physiological and biochemical changes such as ethylene production, pigment accumulation, production of volatile components and phenolic compounds, softening etc., occur through actions of enzymes and transcriptional reprogramming of genes, which are involved in the sucrose, starch, amino acid, methionine and cysteine metabolisms, phenylpropanoid biosynthesis, hormone signal transduction and photosynthesis (Tilahun et al., 2020; Choi et al., 2023). One of the most important physiological processes of kiwi ripening after harvest is softening (Yang and Lim, 2017). It is mainly caused by the modifications in cell wall due to the degradation of cell walls and starch. As a key prompter, ethylene coordinates the expression of some celluler metabolic enzymes containing pectolytic enzymes that cause tissue softening by degrading the pectic compounds (Choi et al., 2023). It also directs the expression of genes account for transformation of starch to sugars, increasing respiratory rate, autocatalytic production of ethylene, carotene synthesis and chlorophyll degradation (Abhishek et al., 2016). Etyhlene triggers a transcriptional cascade regulating the expression of many of genes included in aroma, flavor and color properties (Atkinson et al., 2011). Furthermore, ethylene initiates and coordinates intricate biochemical and genetic changes during climacteric ripening, thereby providing a biochemical basis to stimulate fruit ripening (Albert et al., 2011).

In studies conducted to date, the effects of artificial ethylene treatments on the physicochemical, sensorial, fluorometric and genetic properties of Hayward kiwi have been investigated (Ciardiello et al., 2009; Albert et al., 2011; Koutsoflini et al., 2013; Park et al., 2013; Park et al., 2016; Zoffoli et al.,

2016; Shin et al., 2020; Choi et al., 2022; Choi et al., 2023), while natural ripening methods are quite limited (Bostan et al., 2019). However, contrary to these treatments used both in literature and in practice, consumers are demanding naturally grown fruits rather than artificial ripening practices due to health and environmental concerns (Park et al., 2016). In addition, it is expressed that the cost and availability problems of ethylene used worldwide lead producers to apply the treatments, which are extremely harmful to health, such as calcium carbide, which contains harmful components like arsenic and phosphorous (Abhishek et al., 2016). On the other hand, in present studies, the changes in textural properties, except for firmness, depending on exogenous ethylene treatment, have not been investigated sufficiently. Conversely, textural properties are recognized as the paramount sensory quality parameters for fruits, significantly influencing both shelf life and consumer preference (Ciacciulli et al., 2018). Even if a food product is of excellent microbiological, physical and chemical quality, it may not be desirable in sensory terms (Ertaş and Doğruer, 2010). In these contexts, in this study, the possibility of using apple and quince fruits, as ethylene sources, in the healthy, low-cost and accessible ripening process of kiwi that takes a long time to ripen due to the low levels of ethylene production after harvest and the effects of different storage temperatures on ripening process were investigated. The ripening process was monitored through textural analyses and the changes that occur in the textural properties of the fruit during this process were examined.

MATERIALS AND METHODS

Materials

Uniform size, medium weight (90-130g) and undamaged kiwi fruits (*Actinidia deliciosa)* (cv. 'Hayward'), which are characterized by distinctive features such as a weight of about 120 g, larger and more cylindrical shape than an egg and greenish-brown skin coated with the hairs (Jaeger and Harker, 2005), were obtained from the local market in Erzurum. The primary criterion for selecting kiwi fruits was that they were unripe. This condition was confirmed by measuring their firmness as being over 40 N, which is the average firmness value of an unripe kiwi after harvest (Lim et al., 2017). Similarly, uniform and undamaged apple (*Starking delicious*) and quince (*Cydonia oblonga* Miller) samples were obtained from the local market. They were purchased directly after harvest through consultation with producers. After the obtained fruits were brought to the laboratory, they were divided into six batches. The first two groups contained only 5 kiwi fruits, the second two groups contained 5 kiwi and 5 apple fruits and the third two groups contained 5 kiwi and 5 quince samples were placed in tightly sealed, double-layered polyethylene bags. Then, one bag from each group was stored at room temperature (20ºC), and the other bag was stored in the refrigerator (4ºC) for 15, 30 and 45 days, which are the period and storage temperatures most commonly used in practice. The samples analyzed without any storage were accepted as control sample. The experiments were conducted in two replications and three parallels.

Methods

Texture Profile Analysis (TPA)

Whole kiwi samples were placed horizontally in the measuring area of the texture analyzer (TA.XTplus, Stable Micro Systems Ltd, Godalming, Surrey, U.K.) equipped with a cylindrical aluminum probe (50 mm) (P/50). In the TPA test, 1mm/s pre-test and test speed, 2mm/s post-test speed, 15% compression ratio and 10 g trigger force were used. As demonstrated in Figure 1, firmness (N), cohesiveness (A2/A1), elasticity (L2/L1), chewiness (firmness x cohesiveness x elasticity) (N) and gumminess values (firmness x cohesiveness) (N) were calculated from the obtained curve.

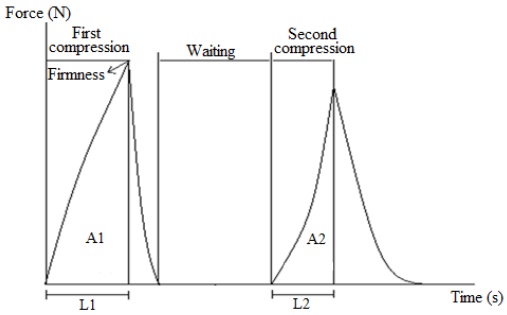

Figure 1. A typical texture profile analysis curve and determining the parameters

Stress Relaxation Test

The stress relaxation test was carried out on whole kiwi samples in horizontal position with the texture analyzer (TA.XTplus, Stable Micro Systems Ltd, Godalming, Surrey, U.K.) equipped with a cylindrical aluminum probe (50 mm) (P/50) under the following conditions: pre-test speed: 1 mm/s, test speed: 0.50 mm/s, holding time: 200 s, distance: 3 mm, trigger force: 10 g. As demonstrated in Figure 2, relaxation time (s) (time required for the maximum force to decrease to itself 66.72 %), maximum force (N) and minimum force (N) values were calculated from the obtained curve.

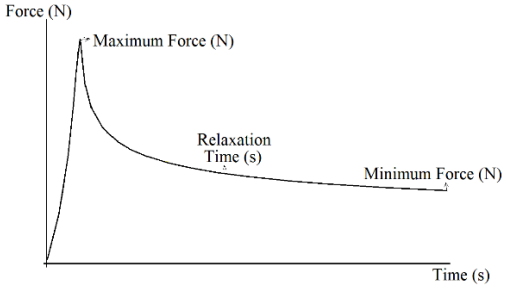

Figure 2. A typical stress relaxation test curve and determining the parameters

Penetration Test

The penetration test was made on whole kiwi samples in horizontal position with the texture analyzer (TA.XTplus, Stable Micro Systems Ltd, Godalming, Surrey, U.K.) equipped with a cylindrical aluminum probe (2 mm) (P/2) under conditions: 2 mm/s pre-test speed, 1 mm/s test speed, 10 g trigger force, 20 mm penetration distance. As demonstrated in Figure 3, penetration force (g) and penetration work (g.s) values of the samples were calculated from the obtained curve.

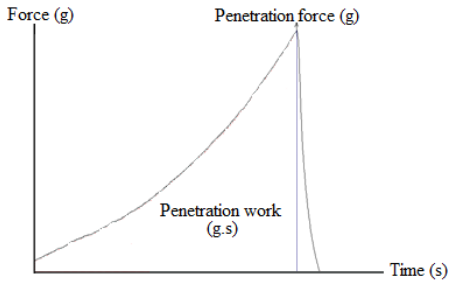

Figure 3. A typical penetration test curve and determining the parameters

Statistical Analysis

Data were analyzed using analysis of variance with IBM® SPSS Statistics software version 22.0.0.0. Significant means of the main sources of variation were compared using the Duncan's Multiple Range Test. The relationship between textural properties of kiwi samples was assessed using Pearson's Correlation Test. The results were expressed as mean ± standard error (SE).

RESULTS AND DISCUSSION

Results of Texture Profile Analysis

Texture is the functional and sensory manifestation of surface, mechanical and structural properties of a foodstuff determined via senses of touch, hearing, vision and kinesthetics (Szczesniak, 2002). The textural properties of a foodstuff are one of the main indicators that determine its acceptance by consumers (Llull et al., 2002). They determine the quality level and type of a product (Ertaş and Doğruer, 2010). As with many food items, textural properties are also one of the most critical quality parameters for fruits especially considering shelf life and consumer choice (Ciacciulli et al., 2018) and even small deflection from expected textural properties may lead to product rejection (Goulao et al., 2010). The effect of different treatments, storage temperatures and periods on the kiwi's firmness value, which is an appropriate parameter to determine ripeness of kiwi (Bostan et al., 2019), is given in Figure 4. It was determined that in all stored samples, the firmness values decreased as a result of the ripening process. Softening, i.e. loss of firmness, is one of most important physiological processes that occurs during kiwi ripening (Yang and Lim, 2017). It is governed by the actions of enzymes and genes (Tilahun et al., 2020; Choi et al., 2023). Textural properties in fruits are fundamentally associated with structural composition of cell wall and middle lamella (Gokul Nath et al., 2023) and exposed to the various modifications due to the degradation of cell walls during the ripening process. In the course of ripening, ethylene, which can be produced autocatalytically or applied exogenously, triggers the expression of some celluler metabolic enzymes containing polygalacturonase, pectin methyl esterase, xyloglucan hydrolase/transglucosylase, expansin and pectate lyase. By the effect of these enzymes, pectic galactose side chains loss, hemicellulose and pectin undergo depolymerization and intercellular adhesion decreases, eventually leading to the softening in texture. Another factor in the cell wall structural composition change that causes fruit softening is the degradation of starch (Choi et al., 2023). Ethylene also contributes to softening by promoting the expression of genes account for transformation of starch to sugar (Abhishek et al., 2016), which sugar accumulation is one of the most obvious indicators that kiwi is ripe for eating (Bostan et al., 2019). As it can be seen from the general effect of the treatment type on the firmness values in Figure 4, kiwi samples stored alone (150.46 N) and with quince (151.59 N) exhibited statistically similar and higher firmness values than the samples stored with apple (108.16 N). That is, contrary to expectations, storage process with quince did not cause the kiwi to soften; on the contrary, although it was not statistically significant, the samples stored with quince were firmer than the samples stored alone in general. The increase in the firmness of kiwi samples stored with quince raises the possibility that quince may have also absorbed the ethylene produced at minimum levels by kiwi in addition to using ethylene produced endogenously and autocatalytically by itself. It is known that quince is ordinarily a climacteric fruit (Carmen et al., 2015). However, ethylene production rate of quince is low for probably reasons such as insufficient amount of 1-aminocyclopropane-1-carboxylic acid oxidase, which is involved in ethylene biosynthesis of quince, or amount of 1-aminocyclopropane-1-carboxylic acid synthase and/or 1-aminocyclopropane-1-carboxylic acid activity or level (Tuna Gunes and Koksal, 2005), which may have led it to act as an ethylene receiver rather than an ethylene transmitter. On the other side, the significant decreases in the firmness values of the samples stored with apple can be associated with the fact that apple is a fruit with a very high ethylene production capacity (Wray French, 2013; Navarro Martínez et al., 2021), which firmness-reducing effect of ethylene has already been mentioned earlier. In a similar study conducted by Gandhi et al. (2016) in which apple, pear, tomato and calcium carbide were used to ripen banana, apple was

particularly recommended in terms of the natural and faster ripening process. As it can be seen from the general effect of storage temperature presented in Figure 4, kiwi samples stored at room temperature had statistically lower firmness values than the samples stored in the refrigerator. This can be attributed to the fact that the samples stored at room temperature release more ethylene. Honda et al., (2014) reported that a hotter environment increases ethylene production of apple during ripening process. Similarly, it is stated that the for quinces, the best ripening temperature is 20ºC (Carmen et al., 2015). In addition, it is known that most of enzymes operate at 30-70°C optimally (Uragami et al., 2013) and lower temperatures decrease enzyme activity due to insufficient activation energy (Moy and Nkongolo, 2022). Therefore, it is thought that the fact that the enzymes triggered by ethylene and softening the tissue by changing the cell wall composition are less active at refrigerator temperature, may have also contributed to the higher firmness values in the samples stored in the refrigerator. With regard to the storage time variable, there was no significant statistical difference between the samples stored in the refrigerator for 30 and 45 days and between those stored at room temperature with quince for 30 and 45 days. In addition, there was no statistically significant change in the firmness values of kiwi samples stored alone at room temperature depending on storage time. A similar tendency was also observed in the samples stored with apple at room temperature. Along with all these, increasing the storage time resulted in a general decrease in the firmness values of the samples depending on the continuation of the ripening process.

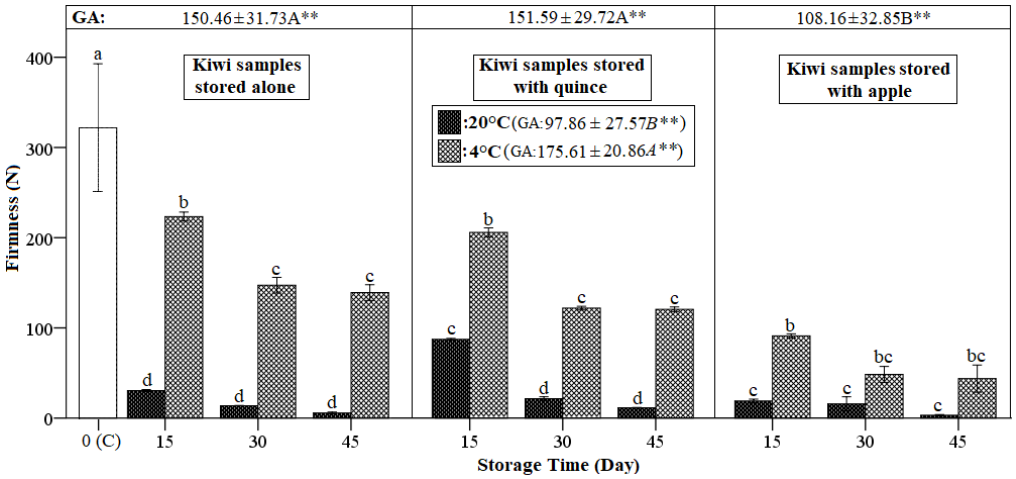

Figure 4. The firmness values of kiwi samples stored under different conditions
(Each treatment group was compared within itself) (C:Control (for all treatment groups), GA:General average)

As it is seen in Figure 5, in all stored samples, chewiness and gumminess values decreased compared to the control sample. In general, kiwi samples stored alone and with quince exhibited higher chewiness and gumminess values than the samples stored with apple, but it was not statistically significant. Kiwi samples stored in the refrigerator had statistically higher chewiness and gumminess values than the samples stored at room temperature. It was determined that as the storage time increased, the chewiness and gumminess values of the samples generally decreased. However, no significant statistical differences occurred in general, especially in the chewiness values. Chewiness refers to the total work (energy) needed for the act of chewing to decrease the consistency of a solid food into a form that can be swallowed. It is a mathematical inference derived from the firmness, cohesiveness and elasticity parameters (Pandey et al., 2014). Gumminess refers to the energy needed to turn a semi-solid food into a form that can be swallowed. Similarly, gumminess is also a formulation output obtained using the firmness and cohesiveness parameters (Hwang et al., 2012). That is, both parameters are characterized by the basic textural properties from which they are

obtained, specifically by firmness. As a matter of fact, the higher firmness values imply the higher chewiness values (Zaini et al., 2020). Likewise, the higher gumminess values result from higher firmness values (Chandra and Shamasundar, 2015). Therefore, the change trend in the chewiness and gumminess values of the kiwi samples depending on the applied treatment, storage temperature and period variables can be explained by the changes in the firmness values, which their tendencies were similar (Figure 4). Supportively, significant interrelations were determined between the firmness and chewiness values ($r = 0.967$) ($p < 0.01$), firmness and gumminess values ($r = 0.980$) ($p < 0.01$) and chewiness and gumminess values ($r = 0.998$) ($p < 0.01$) (Figure 8).

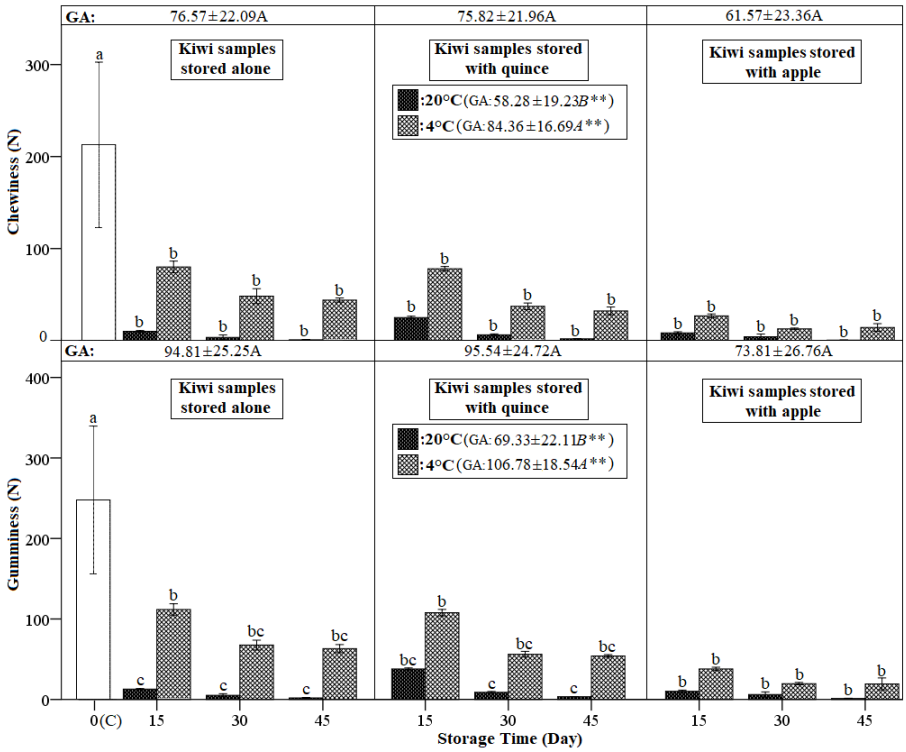

Figure 5. The chewiness and gumminess values of kiwi samples stored under different conditions
(Each treatment group was compared within itself) (C:Control (for all treatment groups), GA:General average)

As it is seen in Table 1, in all stored samples, cohesiveness values decreased compared to the control sample. Although it was not statistically significant, kiwi samples stored with quince exhibited higher cohesiveness values. In general, kiwi samples stored in the refrigerator had statistically higher cohesiveness values than the samples stored at room temperature. Cohesiveness values generally decreased as the storage time increased in all treatment groups. Cohesiveness expresses the strength of the internal links forming the body of the food (Bourouis et al., 2023). It indicates how the material resist a second deformation compared its resistance to the first deformation (Cortez-Trejo et al., 2023) and is mainly related the intramolecular attractions and inner viscosity (Lanza et al., 2023). Higher cohesiveness properties imply that food has a more compact structure and denser texture (Laili and Sofyan, 2024). Pectin substances, main components of structural constituent found in cell wall and middle lamella, are mainly responsible for fruit cohesiveness (Maringgal et al., 2020) and it is highly connected to the changes that occur in microstructural properties of fruit in the course of ripening process (Bianchi et al., 2016). During ripening, the cell wall components, which are responsible for the cohesiveness of the fruit, undergo enzymatic degradations (Massiot et al., 1988). As previously mentioned in the firmness section, cell wall degrading pectolytic enzymes such as pectin methyl esterase, pectate lyase, polygalacturonase etc., whose expression is activated by ethylene, cause that pectic galactose side chains loss and hemicellulose and pectin undergo depolymerization (Choi et al.,

2023). As a result of depolymerization and solubilization of polysaccharides, intercellular rupture occurs, cohesive pectin matrix losses and eventually cohesiveness decreases (Bianchi et al., 2016). For these reasons, it is thought that storage process at room temperature, where ethylene release is estimated to be higher as detailed earlier, reduced cohesiveness further. In addition, the general decreases in cohesiveness values of samples depending on the increasing the storage time can be also attributed to the continuity of the mentioned effects with the continuation of ripening. As a solution-oriented approach, Maringgal et al., (2020) stated that calcium may preserve and strengthen cell wall structure of fruits through mechanisms such as decreasing the activity of enzymes that degrade the cell wall, holding the cell together and creating calcium pectate complexes. Finally, Lázaro and De Lorenzo (2015) reported that as the weakening of cohesion forces directly affects the firmness property, a linear correlation between firmness and cohesiveness values may be expected (Bianchi et al., 2016). The mentioned relationship was also detected in our study ($r = 0.932$) ($p < 0.01$) (Figure 8). The decreases in these values were already due to similar reasons, meaning that a linear relationship was naturally expected.

Table 1. The cohesiveness and elasticity values of kiwi samples (Mean ± SE)[a]

Storage Temperature	Storage Time (Day)	Cohesiveness			Elasticity		
		Treatment/Storage Type			Treatment/Storage Type		
		Alone	With quince	With apple	Alone	With quince	With apple
20ºC	Control	0.77±0.06^{a}	0.77±0.06^{a}	0.77±0.06^{a}	0.86±0.03^{a}	0.86±0.03^{a}	0.86±0.03^{a}
	15	0.43±0.01^{bc}	0.44±0.01^{bc}	0.54±0.01^{b}	0.78±0.01^{ab}	0.66±0.01^{bc}	0.82±0.01^{ab}
	30	0.39±0.07^{bc}	0.42±0.01^{c}	0.40±0.01^{c}	0.64±0.14^{bc}	0.70±0.01^{b}	0.66±0.06^{c}
	45	0.33±0.03^{c}	0.31±0.01^{d}	0.37±0.01^{c}	0.48±0.01^{c}	0.55±0.01^{d}	0.40±0.01^{d}
	GA		0.49±0.04^{B**}			0.69±0.03^{B**}	
4ºC	15	0.50±0.01^{b}	0.53±0.02^{b}	0.42±0.01^{c}	0.72±0.01^{ab}	0.73±0.03^{b}	0.71±0.01^{c}
	30	0.46±0.01^{bc}	0.46±0.01^{bc}	0.41±0.02^{c}	0.72±0.03^{ab}	0.66±0.01^{bc}	0.65±0.00^{c}
	45	0.46±0.01^{bc}	0.45±0.01^{bc}	0.44±0.01^{c}	0.70±0.01^{ab}	0.60±0.05^{cd}	0.74±0.03^{bc}
	GA		0.53±0.03^{A**}			0.73±0.02^{A**}	
	GA	*0.51±0.04^{A}*	*0.52±0.04^{A}*	*0.51±0.04^{A}*	*0.72±0.03^{A}*	*0.70±0.03^{A}*	*0.71±0.04^{A}*

[a] Means with different small letters and means with different uppercase letter are statistically different ($p < 0.05$)
**P < 0.01, GA.: General Average (Each treatment group was compared within itself)

As it is seen in Table 1, in stored samples, elasticity values decreased compared to the control sample in general. The treatment type did not affect the elasticity values of the samples statistically significantly. In general, kiwi samples stored in the refrigerator had statistically higher elasticity values than the samples stored at room temperature. Depending on the storage time variable, kiwi samples stored alone in the refrigerator were not affected statistically significantly. While the elasticity values of the samples stored with quince at room temperature first increased and then decreased again, the opposite effect was observed in the samples stored with apples in the refrigerator. With all of these, when the general effect of the storage time on the elasticity values of the samples was examined, it was determined that the elasticity values of the samples generally decreased due to the increase in the storage time compared to the initial levels. Elasticity property of fruit tissues exhibits changes as a function of ripening process (Dakogol et al., 2015). Decrease in the elasticity property is mostly connected to the tissue breakdown (Rico Rodríguez et al., 2015). During ripening process, solubilization and depolymerization of pectin and depolymerization of starch result in increase in the osmotic pressure and decrease in the cell swelling, leading to the disintegration of middle layer cells and cell wall. However, a high elasticity is generally associated to the presence of good cellular

adhesion and structural integrity (Li et al., 2024). For these reasons, kiwi samples stored at higher temperatures that increase ethylene release (Honda et al., 2014), and the samples with increased storage periods that continue to release ethylene, exhibited lower elasticity values, since structural destruction is greater due to the triggering effect of ethylene as detailed earlier. The extent of structural destruction occurring due to the variables mentioned, which is clearly evident from the sharp decreases in the cohesiveness and firmness values of samples (Table 1, Figure 4), reflected in the elasticity property. Already, similar changes have occurred between elasticity and cohesiveness values ($r = 0.817$) ($p < 0.01$) and elasticity and firmness values ($r = 0.718$) ($p < 0.01$) due to the same effect (Figure 8).

Results of Stress Relaxation Test

Stress relaxation test is a rapid method used to determine viscoelastic properties (Magaña Barajas et al., 2012). Main principle of stress relaxation test is the monitoring of the stress relaxation behavior of the material, which is subjected to an initial loading like a tension and compression at a particular strain rate kept constant (Bakbak and Colak, 2023). The relaxation time values of kiwi samples are given in Table 2. It was determined that the relaxation time values significantly decreased in all stored samples. In general, kiwi samples stored alone showed higher relaxation time values, followed by the samples stored with quince and the samples stored with apple, respectively. In addition, kiwi samples stored in the refrigerator had statistically higher relaxation time values than the samples stored at room temperature. There was a general decrease with minor exceptions in the relaxation time values of the samples due to the increase in storage time, especially compared to the control sample. The relaxation time refers to the time required for the maximum force value, which is another parameter of the stress relaxation test, to decrease to 66.72 % of itself. Higher relaxation time value is associated to the bigger structure units, which have a slower molecular motion (Lin et al., 2018). Therefore, the samples stored with apple, the samples stored at room temperature and the samples with advanced storage period, exhibited lower relaxation time values. Because, pectolytic compounds and starch breakdown are estimated to be higher in these samples as detailed firmness section, meaning that the smaller structure units with faster molecular motion. Also, higher relaxation time values are also associated to a more rigid and elastic behavior of the material (Kadiri et al., 2019), because, thanks to its high elasticity, material can structurally tolerate the applied force further and does not immediately show relaxation behavior by resisting and this extends the time required for the maximum force to decrease at the specified rate. In line with literature guidelines, the kiwi samples, which had lower firmness and elasticity values, exhibited lower relaxation time values in general (Figure 4, Table 1). In addition, the relationships between relaxation time and firmness ($r = 0.916$) ($p < 0.01$) and relaxation time and elasticity ($r = 0.757$) ($p < 0.01$) were statistically significant (Figure 8).

As it is seen in Table 3, maximum and minimum force values decreased in all stored samples. The kiwi samples stored with quince exhibited statistically higher maximum and minimum force values, while the samples stored with apple exhibited lower values in general. Kiwi samples stored in the refrigerator had statistically higher values than the samples stored at room temperature in terms of maximum and minimum force. As the storage time increased, the maximum and minimum force values of the samples decreased, except for the sample stored with quince in the refrigerator for 45 days. The general decrease in the maximum and minimum force values of the samples depending on the applied treatment, storage temperature and period can be explained by the change trend in the firmness values. Maximum force, which is the degree of initial resistance shown by sample to applied deformation, and minimum force, which is the degree of resistance shown by sample at the end of test,

are associated to the firmness of the food and increases in these parameters imply that foodstuff exhibits a more solid like structure (Hanoğlu and Karaoğlu, 2024). Therefore, the samples with higher firmness values exhibited higher maximum and minimum force values, while the samples with lower firmness values exhibited lower values (Figure 4). Significant relationships between the maximum force and firmness values ($r = 0.970$) ($p < 0.01$) and minimum force and firmness values ($r = 0.970$) ($p < 0.01$) were also confirmed statistically (Figure 8).

Table 2. The relaxation time values of kiwi samples (Mean ± SE)[a]

Storage Temperature	Storage Time (Day)	Relaxation Time (s)		
		Treatment/Storage Type		
		Alone	With quince	With apple
20ºC	Control	124.83±1.00^{a}	124.83±1.00^{a}	124.83±1.00^{a}
	15	40.45±0.75^{b}	24.69±0.50^{d}	27.32±0.02^{c}
	30	16.87±0.63^{e}	9.07±0.07^{f}	12.55±0.50^{e}
	45	12.42±0.13^{f}	11.47±0.02^{e}	8.40±1.00^{f}
	GA		44.81±9.80^{B**}	
4ºC	15	33.64±2.50^{c}	32.42±0.01^{c}	28.91±0.25^{bc}
	30	26.03±1.00^{d}	31.46±0.01^{c}	19.05±0.05^{d}
	45	25.55±1.25^{d}	35.83±0.02^{b}	30.70±0.70^{b}
	GA		53.17±8.67^{A**}	
	GA	*50.58±11.27^{A**}*	*49.32±11.49^{B**}*	*47.07±11.75^{C**}*

[a] Means with different small letters and means with different uppercase letter are statistically different ($p < 0.05$)
**$P < 0.01$, GA.: General Average (Each treatment group was compared within itself)

Table 3. The maximum force and minimum force values of kiwi samples (Mean ± SE)[a]

Storage Temp.	Storage Time (Day)	Maximum Force (N)			Minimum Force (N)		
		Treatment/Storage Type			Treatment/Storage Type		
		Alone	With quince	With apple	Alone	With quince	With apple
20ºC	Control	77.50±1.00^{a}	77.50±1.00^{a}	77.50±1.00^{a}	50.07±1.00^{a}	50.07±1.00^{a}	50.07±1.00^{a}
	15	14.87±0.85^{e}	32.01±0.51^{e}	12.71±0.71^{d}	8.23±0.95d	16.95±0.95^{e}	7.43±0.00^{d}
	30	4.83±0.50^{f}	5.60±0.30^{f}	6.98±0.50^{e}	2.05±0.68^{e}	1.71±0.21^{f}	2.74±0.50^{e}
	45	2.80±0.10^{f}	1.08±0.08^{g}	1.05±0.05^{f}	1.15±0.05^{e}	0.55±0.05^{f}	0.41±0.02^{e}
	GA		26.20±6.40^{B**}			15.95±4.21^{B**}	
4ºC	15	40.79±2.00^{b}	45.59±0.59^{c}	29.70±4.27^{b}	22.21±2.75^{b}	26.62±0.12^{c}	16.80±2.35^{b}
	30	29.05±1.00^{c}	40.64±0.01^{d}	21.40±0.40^{c}	15.93±1.00^{c}	23.20±0.20^{d}	11.34±0.04^{c}
	45	23.57±1.00^{d}	50.62±0.00^{b}	11.25±0.25^{de}	13.00±0.95^{c}	29.51±0.01^{b}	6.58±0.08^{d}
	GA		43.76±4.62^{A**}			26.28±3.15^{A**}	
	GA	*33.86±7.17^{B**}*	*41.32±6.90^{A**}*	*29.76±7.43^{C**}*	*20.34±4.75^{B**}*	*24.83±4.56^{A**}*	*18.18±4.91^{C**}*

[a] Means with different small letters and means with different uppercase letter are statistically different ($p < 0.05$)
**$P < 0.01$, GA.: General Average (Each treatment group was compared within itself)

Results of Penetration Test

The penetration force values of kiwi samples subjected to different storage conditions are given in Figure 6. It was determined that in all stored samples, penetration force values decreased compared to the control sample, especially more pronounced in the samples stored with apple. In general, the kiwi samples stored with quince exhibited statistically higher penetration force values, while the samples stored with apple exhibited lower values. In addition, kiwi samples stored in the refrigerator had statistically higher values than the samples stored at room temperature in terms of penetration force. Although especially kiwi samples stored with apple at room temperature were not very

significantly affected, there was a general decrease with minor exceptions in the penetration force values of the samples depending on the increase in the storage time.

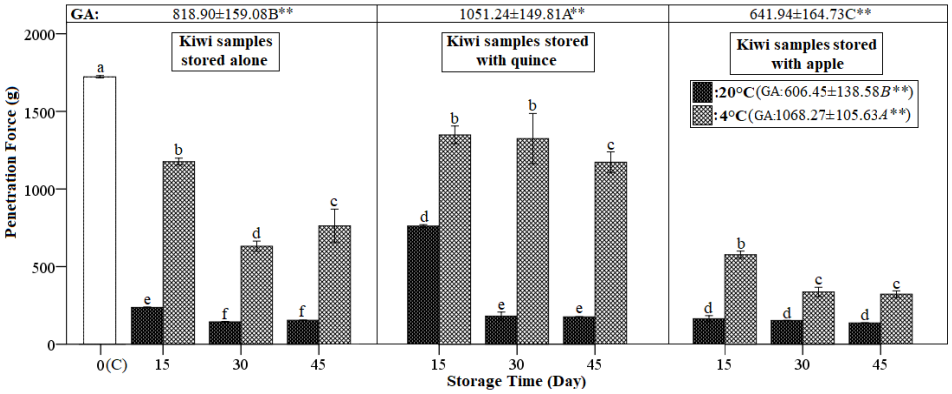

Figure 6. The penetration force values of kiwi samples stored under different conditions (Each treatment group was compared within itself) (C:Control (for all treatment groups), GA:General average)

The penetration work values of kiwi samples stored on different conditions are given in Figure 7. It was determined that in all stored samples, penetration work values decreased compared to the control sample. In general, the kiwi samples stored with quince exhibited statistically higher penetration work values, followed by the samples stored alone and the samples stored with apple, respectively. Kiwi samples stored in the refrigerator exhibited statistically higher penetration work values than the samples stored at room temperature in general. Although especially kiwi samples stored alone at room temperature were not very significantly affected, the increase in the storage time caused an overall decrease with minor exceptions in the penetration work values of the samples compared to initial level. The general decreases in the penetration force and penetration work values of the samples depending on the applied treatment, storage temperature and period are due to the decreases in the firmness property (Figure 4), especially firmness of fruit skin, which is first respondent of penetration test. During ripening process, polysaccharides in the cell wall undergo degradation with the effect of different carbohydrate hydrolases and turgor pressure reduces due to the polysaccharide degradation and osmotic dehydration, leading to the cell wall of fruit to break down and accordingly skin firmness of fruit to reduce (Chung et al., 2021). In addition, as earlier mentioned, in particular, the breakdown and solubilization of pectin due to enzymatic degradations lead to a general softening in the fruit texture during ripening process (Verma et al., 2014). All of these result in the increasing the penetrability of samples, which means that the force and energy required for penetration action are reduced especially considering an unripe kiwi. The significant correlations between penetration force and firmness values ($r = 0.964$) ($p < 0.01$) and penetration work and firmness values ($r = 0.975$) ($p < 0.01$) support this phenomenon (Figure 8).

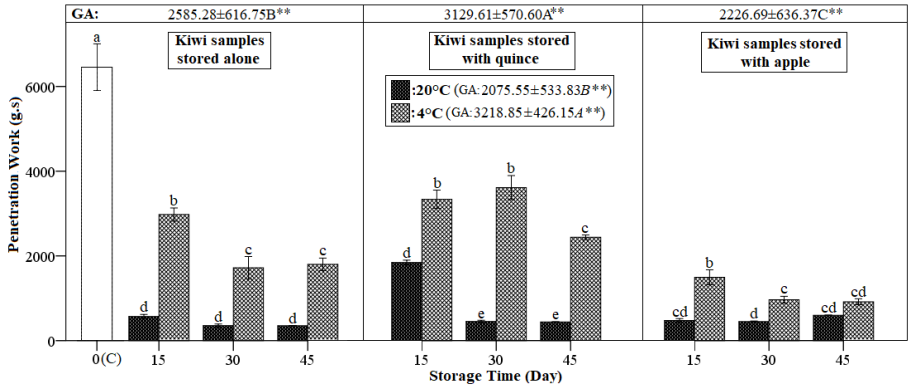

Figure 7. The penetration work values of kiwi samples stored under different conditions

(Each treatment group was compared within itself) (C:Control (for all treatment groups), GA:General average)

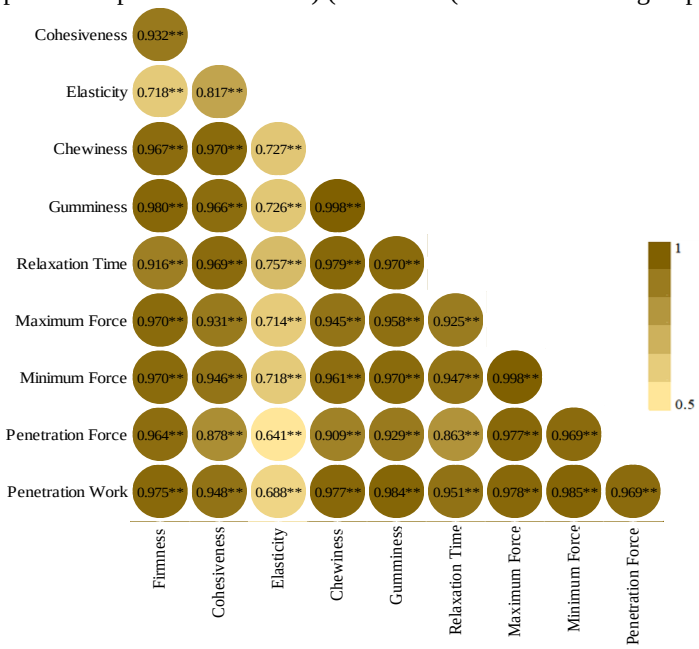

Figure 8. Correlation matrix of textural characteristics of kiwi samples (**p<0.01)

CONCLUSION

The possibility of using apple and quince in the natural ripening process of climacteric kiwi fruit, which takes a long time to ripen due to low ethylene release level after harvest, was investigated. The ripening process was monitored by textural analyses. It was determined that in general, storage process accompanied by apple decreased the firmness, chewiness and gumminess values of the kiwi samples, contributing the ripening process. On the contrary, storage process accompanied by quince did not show a decreasing effect on these values. The increase in the storage time was effective in reducing texture profile analysis test parameters in general. The samples stored in the refrigerator had higher values than samples stored at room temperature in terms of textural parameters. The relaxation time, maximum force, minimum force, penetration force and penetration work values of the samples were characterized by the texture profile analysis outcomes especially firmness, cohesiveness and elasticity.

As a general inference, it has been concluded that storage process accompanied by apple is a quite good option in the natural, accessible and faster ripening process of kiwi fruit. As an important outcome, approximately 28% overall decrease rate in fruit firmness was achieved in the storage process with apple, demonstrating that apple has an obvious triggering effect on kiwi ripening. In cases in which the current ripeness level of kiwi is desired to be maintained, storage treatment accompanied by quince can be recommended. Also, valid for all three storage conditions (alone, with quince, with apple), it would be correct to suggest the choosing room temperature condition in order to ripen quickly, while refrigerator condition should be chosen to slow down the ripening process relatively. It is thought that the results obtained from this study may encourage further research in which apple will be used in the natural ripening process of other climatic fruits that take a long time to ripen.

Conflict of Interest

The article authors declare that there is no conflict of interest between them**.**

Author's Contributions

The authors have contributed equally to the article.

REFERENCES

Abhishek, R. U., Venkatesh, H. N., Manjunath, K., & Mohana, D. C. (2016). Artificial ripening of fruits-misleading ripe and health risk. Everyman's Science, 6, 364-369.

Albert, Z. S., Beh, M., Kuznyák, L., & Papp, I. (2011, September). Ripening of kiwi fruits by ethylene treatment. In II Balkan Symposium on Fruit Growing 981 (pp. 699-703).

Atkinson, R. G., Gunaseelan, K., Wang, M. Y., Luo, L., Wang, T., Norling, C. L., ... & Schaffer, R. J. (2011). Dissecting the role of climacteric ethylene in kiwifruit (Actinidia chinensis) ripening using a 1-aminocyclopropane-1-carboxylic acid oxidase knockdown line. Journal of Experimental Botany, 62(11), 3821-3835.

Bakbak, O., & Colak, O. (2023). Modeling wide range of viscoelastic–viscoplastic behavior of Araldite LY 564 epoxy using cooperative viscoplasticity theory based on overstress model. Journal of Applied Polymer Science, 140(9), e53557.

Bianchi, T., Guerrero, L., Gratacós-Cubarsí, M., Claret, A., Argyris, J., Garcia-Mas, J., & Hortós, M. (2016). Textural properties of different melon (Cucumis melo L.) fruit types: Sensory and physical-chemical evaluation. Scientia Horticulturae, 201, 46-56.

Bostan, S. Z., Mazı, B. G., & Güler, S. K. (2019). The ripening of kiwifruit by apple and calcium carbide. Manas Journal of Agriculture Veterinary and Life Sciences, 9(1), 1-7.

Bourouis, I., Li, B., Pang, Z., Chen, C., & Liu, X. (2023). Effect of soy peptides with different hydrolysis degrees on the rheological, tribological, and textural properties of soy protein isolate gels. Journal of Food Science, 88(12), 5122-5135.

Carmen, B., Sumalan, R., & Renata, S. (2015). Studies on postharvest quality of some quince genotypes. Journal of Horticulture, Forestry and Biotechnology, 19(1), 193-196.

Chandra, M. V., & Shamasundar, B. A. (2015). Texture profile analysis and functional properties of gelatin from the skin of three species of fresh water fish. International Journal of Food Properties, 18(3), 572-584.

Chen, Y., Grimplet, J., David, K., Castellarin, S. D., Terol, J., Wong, D. C., ... & Chervin, C. (2018). Ethylene receptors and related proteins in climacteric and non-climacteric fruits. Plant Science, 276, 63-72.

Choi, D., Choi, J. H., Park, K. J., Kim, C., Lim, J. H., & Kim, D. H. (2023). Transcriptomic analysis of effects of 1-methylcyclopropene (1-MCP) and ethylene treatment on kiwifruit (Actinidia chinensis) ripening. Frontiers in Plant Science, 13, 1084997.

Choi, H. R., Baek, M. W., Jeong, C. S., & Tilahun, S. (2022). Comparative transcriptome analysis of softening and ripening-related genes in kiwifruit cultivars treated with ethylene. Current Issues in Molecular Biology, 44(6), 2593-2613.

Chung, S. W., Oh, H., Lim, C. K., Jeon, M. K., & An, H. J. (2021). Fruit characteristics of ten greenhouse-grown mango varieties during postharvest ripening at ambient temperature and relative humidity. International Journal of Fruit Science, 21(1), 1073-1085.

Ciacciulli, A., Cirilli, M., Chiozzotto, R., Attanasio, G., Da Silva Linge, C., Pacheco, I., ... & Bassi, D. (2018). Linkage and association mapping for the slow softening (SwS) trait in peach (P. persica L. Batsch) fruit. Tree Genetics & Genomes, 14, 1-10.

Ciardiello, M. A., Giangrieco, I., Tuppo, L., Tamburrini, M., Buccheri, M., Palazzo, P., ... & Mari, A. (2009). Influence of the natural ripening stage, cold storage, and ethylene treatment on the protein and IgE-binding profiles of green and gold kiwi fruit extracts. Journal of Agricultural and Food Chemistry, 57(4), 1565-1571.

Cortez-Trejo, M. C., Figueroa-Cárdenas, J. D., & Mendoza, S. (2023). Electrostatic hydrogels based on amaranth proteins and xanthan gum: Water-binding, microstructural, rheological and textural properties. *Journal of Polymers and the Environment, 31*(9), 3937-3950.

Dakogol, F. A., Obetta, S. E., & Ijabo, O. J. (2015). Creep properties of local variety of lime (Lemun tsami) under quasi-static loading. International Journal of Scientific Engineering and Technology, 4(9), 466-471.

Ertaş, N., & Doğruer, Y. (2010). Besinlerde tekstür. Erciyes Üniversitesi Veteriner Fakültesi Dergisi, 7(1), 35-42.

Gandhi, S., Sharma, M., & Bhatnagar, B. (2016). Comparative study on the ripening ability of artificial ripening agent (Calcium Carbide) and natural ripening agents. GJBAHS, 5(2), 106-110.

Gokul Nath, K., Pandiselvam, R., & Sunil, C. K. (2023). High-pressure processing: Effect on textural properties of food-A review. Journal of Food Engineering, 351, 111521.

Goulao, L. F., Almeida, D. P., & Oliveira, C. M. (2010). Effect of enzymatic reactions ontexture of fruits and vegetables. In Enzymes in fruit and vegetable processing (pp. 85-136). CRC Press.

Hanoğlu, A., & Karaoğlu, M. M. (2024). The effect of different pulp powders incorporation on the instrumental texture and rheological properties of Turkish delight. International Journal of Gastronomy and Food Science, 35, 100872.

Honda, C., Bessho, H., Murai, M., Iwanami, H., Moriya, S., Abe, K., ... & Tatsuki, M. (2014). Effect of temperature on anthocyanin synthesis and ethylene production in the fruit of early-and medium-maturing apple cultivars during ripening stages. HortScience, 49(12), 1510-1517.

Hwang, J., Kim, D. K., Bae, J. H., Kang, S. H., Seo, K. M., Kim, B. K., & Lee, S. Y. (2012). The effect of rheological properties of foods on bolus characteristics after mastication. Annals of Rehabilitation Medicine, 36(6), 776-784.

Jaeger, S. R., & Harker, F. R. (2005). Consumer evaluation of novel kiwifruit: willingness-to-pay. Journal of the Science of Food and Agriculture, 85(15), 2519-2526

Kadiri, O., Gbadamosi, S. O., & Akanbi, C. T. (2020). Texture profile analysis and stress relaxation characteristics of protein fortified sweet potato noodles. Journal of Texture Studies, 51(2), 314-322.

Koutsoflini, A., Gerasopoulos, D., & Vasilakakis, M. (2013). The effects of fruit maturation, delayed storage and ethylene treatment on the incidence of low-temperature breakdown of 'Hayward'kiwifruit. Journal of the Science of Food and Agriculture, 93(2), 410-414.

Laili, N. A., & Sofyan, A. (2024). The effect of kepok banana starch substitution (Musa paradisiaca L.) modifications on the texture and color of mocaf flour caramel sponge. Engineering Proceedings, 63(1), 16.

Lanza, B., Bacceli, M., & Simone, N. (2023). Development of a Specific Lexicon to Describe Sensory and Textural Characteristics of Olive Paté. *Applied Sciences*, *13*(21), 11745.

Lázaro, A., & De Lorenzo, C. (2015). Texture analysis in melon landraces through instrumental and sensory methods. International Journal of Food Properties, 18(7), 1575-1583.

Li, M., Chi, H., Sun, L., Han, C., Wei, B., Zhou, Q., ... & Ji, S. (2024). Spraying 2, 4-epibrassinolide maintains the quality attributes and activates reactive oxygen species metabolism of postharvest strawberries. Scientia Horticulturae, 331, 113123.

Lim, S., Lee, J. G., & Lee, E. J. (2017). Comparison of fruit quality and GC–MS-based metabolite profiling of kiwifruit 'Jecy green': Natural and exogenous ethylene-induced ripening. Food Chemistry, 234, 81-92.

Lin, C., He, G., Liu, J., Pan, L., Liu, S., Li, J., & Guo, S. (2018). Construction and non-linear viscoelastic properties of nano-structure polymer bonded explosives filled with graphene. Composites Science and Technology, 160, 152-160.

Llull, P., Simal, S., Benedito, J., & Rosselló, C. (2002). Evaluation of textural properties of a meat-based product (sobrassada) using ultrasonic techniques. Journal of Food Engineering, 53(3), 279-285.

Magaña-Barajas, E., Ramírez-Wong, B., Torres-Chávez, P. I., & Morales-Rosas, I. (2012). Use of the stress-relaxation and dynamic tests to evaluate the viscoelastic properties of dough from soft wheat cultivars. Viscoelasticity: From theory to biological applications. IntechOpen.

Maringgal, B., Hashim, N., Tawakkal, I. S. M. A., Mohamed, M. T. M., Hamzah, M. H., Ali, M. M., & Abd Razak, M. F. H. (2020). Kinetics of quality changes in papayas (Carica papaya L.) coated with Malaysian stingless bee honey. Scientia Horticulturae, 267, 109321.

Massiot, P., Rouau, X., & Thibault, J. F. (1988). Isolation and characterisation of the cell-wall fibres of carrot. Carbohydrate Research, 172(2), 217-227.

Moy, A., Nkongolo, K. (2022). Influence of decreasing temperature on soil microbial activity in a boreal shield ecozone. American Journal of Environmental Sciences, 42-51.

Navarro-Martínez, A., López-Gómez, A., & Martínez-Hernández, G. B. (2021). Potential of essential oils from active packaging to highly reduce ethylene biosynthesis in broccoli and apples. ACS Food Science & Technology, 1(6), 1050-1058.

Pandey, M. C., Harilal, P. T., & Radhakrishna, K. (2014). Effect of processing conditions on physico-chemical and textural properties of shami kebab. International Food Research Journal, 21(1), 223.

Park, Y. S., Im, M. H., Choi, J. H., Yim, S. H., Leontowicz, H., Leontowicz, M., ... & Gorinstein, S. (2013). The effects of ethylene treatment on the bioactivity of conventional and organic growing 'Hayward'kiwi fruit. Scientia Horticulturae, 164, 589-595.

Park, Y. S., Polovka, M., Ham, K. S. H., Park, Y. K., Vearasilp, S., Namieśnik, J., ... & Gorinstein, S. (2016). Impact of cultivation conditions, ethylene treatment, and postharvest storage on selected quality and bioactivity parameters of kiwifruit "Hayward" evaluated by analytical and chemometric methods. Journal of AOAC International, 99(5), 1310-1320.

Rico Rodríguez, F., Gutiérrez Cortés, C., & Díaz Moreno, C. (2015). Influence of chitosan coatings with citric essential oil on the shelf-life of minimally processed mango (Mangifera indica L.). Revista Facultad Nacional de Agronomía Medellín, 68(2), 7679-7688.

Shin, M. H., Muneer, S., Kim, Y. H., Lee, J. J., Bae, D. W., Kwack, Y. B., ... & Kim, J. G. (2020). Proteomic analysis reveals dynamic regulation of fruit ripening in response to exogenous ethylene in kiwifruit cultivars. Horticulture, Environment, and Biotechnology, 61, 93-114.

Szczesniak, A. S. (2002). Texture is a sensory property. Food Quality and Preference, 13(4), 215-225.

Tilahun, S., Choi, H. R., Kwon, H., Park, S. M., Park, D. S., & Jeong, C. S. (2020). Transcriptome analysis of 'Haegeum'gold kiwifruit following ethylene treatment to improve postharvest ripening quality. Agronomy, 10(4), 487.

Tuna Gunes, N., & Koksal, A. I. (2005). Ethylene biosynthesis of quince during storage. Acta Horticulturae, 682(1), 177.

Uragami, T., Chakraborty, S., Piemonte, V., & Di Paola, L. (2013). Biocatalytic membrane reactors: Principles, preparation and biotechnological, pharmaceutical and medical applications. In Handbook of Membrane Reactors (pp. 846-887). Woodhead Publishing.

Vasile Scăețeanu, G., Madjar, R. M., Stănică, F., & Peticilă, A. G. (2019). An overview on chemical composition and health importance of kiwifruit. Proc. Rom. Acad., Series B, 21(1), p. 73–81.

Verma, C., Singh, R. K., & Mishra, S. (2014). Biochemical characterization of pectin methylesterase from Musa acuminata referring to delayed ripening. Journal of Pharmacy and Biological Sciences, 9(1), 42-47.

Wray French, L. (2013). A review of ethylene management techniques controlling the shelf life of perishables and research into two new types of ethylene scrubbing technologies. Food Safety and Quality Management Masters.

Yang, Y. J., & Lim, B. S. (2017). Effects of high carbon dioxide and ethylene treatment on postharvest ripening regulation of red kiwifruit (Actinidia melanandra Franch) during cold storage. Journal of the Korea Academia-Industrial Cooperation Society, 18(6), 478-485.

Zaini, H. B. M., Sintang, M. D. B., & Pindi, W. (2020). The roles of banana peel powders to alter technological functionality, sensory and nutritional quality of chicken sausage. Food Science & Nutrition, 8(10), 5497-5507.

Zoffoli, J. P., Flores, K., & D'Hainaut, D. (2016). Effect of ethylene on ripening of kiwifruit stored under controlled or modified atmosphere packaging and treated with 1-methylcyclopropene. Journal of Berry Research, 6(4), 381-393.