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RESEARCH ARTICLE

Correlation analysis of texture and chemical properties of olecranon honey peach cultivars from different provinces in China

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ABSTRACT

Texture is key to the fruit quality for the olecranon honey peach. In this study, olecranon honey peach was harvested from 11 Chinese Provinces and the effect of the olecranon honey peach planting areas on fruit texture and the relationship between texture and chemical parameters was investigated. In the texture section, peaches were measured by texture profile analysis (TPA) and puncture tests. Predictive models were developed to determine the texture of olecranon honey peach based on chemical properties. The results demonstrated that olecranon honey peach grown in Lianping county had significantly better texture and structure than those grown in other locations, especially the peach which planted in Lianping county with the 4.0 planting technology at high altitude. Correlation results showed that the texture of olecranon honey peach was negatively correlated with water content, while the hardness of texture parameters was positively correlated with pectin content and crispness was negatively correlated with titratable acid. Creating texture models that can estimate the texture value of olecranon honey peach by water content, pectin, and titratable acid.

Keyword: Olecranon honey peach; Texture profile analysis; Chemical properties; Correlation analysis; Texture model

INTRODUCTION

The olecranon honey peach is a common peach variety grown in Lianping County, Guangdong Province, China, and is cultivated in several subtropical cities and provinces throughout China. It has a characteristic tail that looks like an eagle's beak, and desirable characteristics of crispness, hardness, fragrance and a sweet taste (Poles et al., 2020, Wang et al., 2019). In 2019, a new planting technique was developed in Lianping County for cultivating the olecranon honey peach. Peaches grown using this method are registered in China as the olecranon honey peach 4.0.

PeriodNaghdi et al. (2022) reports that traditional planting mainly uses chemical fertilizers, and long-term repeated application of chemical fertilizers will also change the composition of crop microbial communities, making the soil easy to agglomerate. The fruit is easy to be damaged by insects during the growth. Olecranon honey peach 4.0 used bioorganic fermentation fertilizer to increase soil microorganisms and soil fertility. Farmers used bagging technology during fruit growth to reduce the use of pesticides and insect pests. This technology uses EM bacteria (effective microorganisms) for fertilizer fermentation. EM bacteria is a kind of microbial preparation, which can be used for fertilizer fermentation. It is composed of more than 80 microorganisms belonging to 10 genera (Luan et al., 2020). Differences in planting techniques may lead to differences in fruit physicochemical characteristics, such as texture and fruit quality attributes, which influence consumer preference (Jantraa et al., 2018).

In the traditional fruit market, soluble solid content and firmness are quality requirements to fruits (Harker et al., 1997; Hoehn et al., 2003; Rosenthal, 1999)(Chaiya et al., 2018; Harker et al., 1997; Hoehn et al., 2003)(Chaiya et al., 2018; Harker et al., 1997; Hoehn et al., 2003)(Harker et al., 2010; Hoehn et al., 2003). The texture of fruit is related to the structure and size of the cell wall. Since immemorial times, In the 1990s, the cultivation and improvement of olecranon honey peach had begun, Previous studies mainly focused on soft peach, but little

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on the texture of hard peach (Abu-Goukh and Bashir 2003, Batisse et al., 1996, Eisenstecken et al., 2019, O'Donoghue et al., 2020, Szafrańska and Soowiej 2019, Yang et al., 2009). Research suggests that the texture of peaches may be related to chemical parameters, and this trait is of significant interest to breeders and consumers. Although peach texture has been extensively studied, information on olecranon honey peach is limited (Lauxmann et al., 2013, Ma et al., 2020).

Texture profile analyses (TPA) and puncture tests simulate human chewing, and are commonly used for testing mechanical structure by texture analyser (Ballabio et al., 2012, Harker et al., 2006, Kohyama K., et al., 2009, Zhao et al., 2017). Texture determination is widely used in fruits, the determination of fruit texture is beneficial to the study of fruit transportation, preservation and postharvest physiology (Chab et al., 2007, Harker et al., 2019, Ma et al., 2020). A direct relation between firmness and biochemical parameters has been identified Nybom et al. (2020). However, the relationship between texture parameters and chemical characteristics of olecranon honey peach grown in different locations has not been determined.

Therefore, this paper mainly compared the differences of texture and chemical parameters of olecranon honey peach from different places, as well as the main chemical parameters that affect the texture of olecranon honey peach. The characteristic of olecranon honey peach is "crisp and sweet". By studying the relevant influencing factors of this characteristic, we can improve the planting technology of olecranon honey peach, analyse the reasons that affect the quality of olecranon honey peach, guide the improvement and change of planting technology and methods of olecranon honey peach, and make its quality better.

MATERIALS AND METHODS

Sample collection

For this study, olecranon honey peaches were collected from Qingyuan City, Meizhou City, Shaoguan City, Guangxi Province, Yunnan Province, Hunan Province, Jiangxi Province (Table 1), and from two orchards (high and low altitude) in Lianping County including peaches grown using the new technique (olecranon honey peach 4.0) and those grown by the ordinary planting method. Ordinary planting is no fertilizer planting and fruit bagging treatment, but the olecranon honey peach 4.0 technology is to apply biological fermentation fertilizer to fruit trees and bag the fruit. All peaches were at the same ripening stage and purchased between June and August 2020. Intact fruits were selected manually and stored in a controlled atmosphere at 6–10 °C and 80–95% humidity. TPA, puncture tests, and chemical analyses were performed on five fruits from each location. The altitudes of collection sites were assessed by https://www.chahaiba.com and http://haiba.ugoto.cn/in January 2021.

Texture analysis

TPA and puncture test of peaches were performed using a TMS-Pilot Precision texture analyser (Food Technology Corporation, Virginia, USA). Test parameters, descriptions, and formulas are listed in Table 2.

TPA

The texture analyser was loaded with 500 N maximum load rating in tension or compression, and a cylindrical probe (6 cm diameter) was used to carry out the extrusion test. The largest diameter of the peach fruit was cut out (1 cm wide): thereafter, cube sections (1 cm length) were cut out from the section, and the angle between the distances of each cube was 120°(Ma et al., 2020). Samples from three directions were taken from the same fruit cross-section, as shown in Fig. 2. The cube was placed under the tester, and the test speed was set to 60 mm min^{-1}, with a trigger force

Table 1: Sample name, sample type, collection location, and altitude of olecranon honey peaches collected in China

ID	Sample description	Variety of olecranon honey peach	Planting location	Orchard altitude (m)	Sample label
1	High altitude Lianping county	Common	Heyuan city GD	693	HL
2	High altitude Lianping county	4.0	Heyuan city GD	693	HL4.0
3	Low altitude Lianping county	Common	Heyuan city GD	385	LL
4	Low altitude Lianping county	4.0	Heyuan city GD	385	LL4.0
5	Qingyuan county	Common	Qingyuan city GD	313	QY
6	Meizhou county	Common	Meizhou city GD	419	MZ
7	Shaoguan county	Common	Shaoguan city GD	187	SG
8	Guangxi province	Common	Guangxi province	646	GX
9	Yunnan province	Common	Yunnan province	1494	YN
10	Hunan province	Common	Hunan province	642	HN
11	Jiangxi province	Common	Jiangxi province	248	JX

GD, Guangdong province

Table 2: The main parameters of ripe peach samples used in the texture profile analysis (TPA) and puncture test (Giongo et al., 2018, Kohyama et al., 2009)

Parameters	General description	Unit
Texture profile analysis (TPA)		
Hardness (Ha)	Peach under external pressure deformation, to achieve a certain deformation rate of the maximum force required	N
Adhesiveness (Ad)	The maximum value of the rising distance separated from the sensor after a certain force is applied to the peach	N mm
Elasticity (El)	The maximum distance that can restore the original size and shape	mm
Stickiness (St)	Viscous force	N
Chewiness (Ch)	Energy required for chewing	mJ
Puncture test	Slope of the puncture test	
Crispness	Peach under impact force, with no significant deformation and suddenly broken property (TC) Total Crispness (CUS) Upper part of suture (CMS) Middle part of suture (CLS) Lower part of suture (CU) Upper part of surface (CM) Middle part of surface (CL) Lower part of surface	N mm^{-1}
Toughness	Peach is deformed by external force and is not easy to break, area of puncture test (TT) Total toughness (TUS) Upper part of suture (TMS) Middle part of suture (TLS) Lower part of suture (TU) Upper part of surface (TM) Middle part of surface (TL) Lower part of surface	N mm

of 5 N and deformation of 70%. Two extrusion tests were conducted. The measurable parameters included hardness (Ha; N), adhesiveness (Ad; N mm), elasticity (El; mm), stickiness (St; N), and chewiness (Ch; mJ).

Puncture test

The texture analyser was loaded with a 500 N load, and a 3 mm diameter probe was used to puncture the fruit (60 mm min^{-1}). The initial induction force was 5 N, and the puncture depth was 10 mm (Kohyama K., et al., 2009). The puncture distance was calculated when the puncture force was greater than 5 N. Olecranon honey peach has a single carpel; therefore, there will be a suture on the surface of peach fruit after ripening, the difference between suture and non-suture (smooth surface of peach) was considered in the puncture experiments(Liu et al., 2010). A puncture test of upper, middle, and lower parts of the peach suture and non-suture line was performed, as shown in Fig. 3. The measurable parameters include crispness (TC; N mm^{-1}) and toughness (TT; N mm) (Camps C., et al., 2005), calculated using the equations below:

$$TC = Fs / Dp$$

$$TT = \int f(Dp)dDp$$

where *Fs* is the maximum force (N) in the puncture test curve; *Dp* is the probe displacement (mm), which is the distance between the maximum force; *TC* (N mm^{-1}) represents the sudden breakage of fruit in the mouth when the fruit is chewed, so the ratio of the maximum puncture force to the corresponding distance is used as the *TC* value; *TT* (N mm) represents the deformation of the fruit when chewed in the mouth, and is represented as the area formed by the function and the abscissa axis under the maximum puncture force, as indicated by the red area in Fig. 4.

Chemical analysis

The moisture content (MC) of fruit was determined using a moisture meter (JINGTAI, JT-K10, China) in 100 g of peach pulp. The pectin (Pe) and protopectin (Pr) content was determined using an ultraviolet spectrophotometer (SHIMADZU, UV-2600i, China) (Lu et al., 2019, Prawta et al., 2008), and the cellulose, hemicellulose, and lignin content were determined using Van Soest's detergent fibre method (Slavin et al., 1980). Titratable acidity (TA) was determined using phenolphthalein colorimetric titration. Juice extracted from 100 g peach pulp was titrated against 0.1 mol L^{-1} NaOH solution (Zhao et al., 2017). The test was replicated five times for each parameter to obtain the average value. Sugar content (SC) was measured by electronic saccharimeter (TOWA, AMAMIR TD-2000C, Japan). The distance between the cell

Fig 1. Olecranon honey peaches sample photographs.

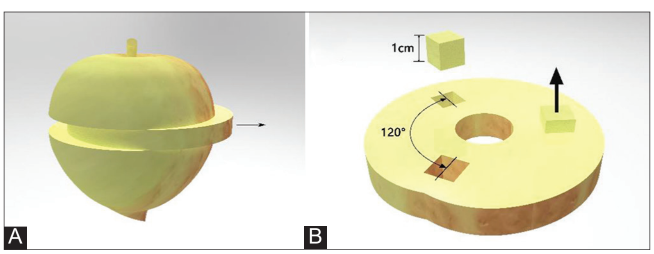

Fig 2. Sampling method of peaches in the texture profile analyses (TPA). (A) the sampling method of peach cross section; (B) the peach sampling area.

wall and cell of the fruit was determined using transmission electron microscopy (TEM) (JEOL, JEM-1200EX, Japan), setting the multiple to Mag: 30000x.

Statistical analysis

Data of the texture and chemical parameters of fruits from the different locations were subjected to analysis of variance (ANOVA) and multivariate analysis of variance

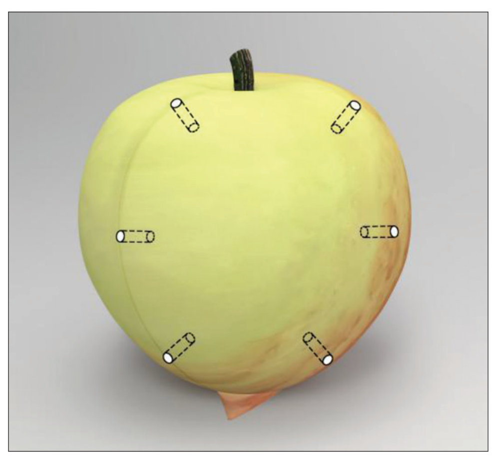

Fig 3. Puncture test sampling method: arrows show the six locations detected by the texture analyser probe. There are three inspection points on the suture line and three inspection points on the smooth surface.

(MANOVA) in SPSS (version 25.0, IBM). Mean values were compared using Duncan's multiple-range test, and means were considered significant at $P < 0.05$. Principal component analysis (PCA) was used to visualise the relationship between texture and chemical parameters. A Pearson's correlation was performed to determine the relationships between texture and chemical parameters of olecranon honey peach. Correlation between parameters were considered significant at $P < 0.05$. A multivariate linear regression (MLR) was used to develop a predictive model for determining the fruit texture of olecranon honey peach based on chemical properties. Error analysis and partial least squares regression verification were carried out on measured and predicted values of the prediction model, the results of model correction were R_c^2, RMSEC, R_p^2 and RMSEP (Mishra et al., 2021).

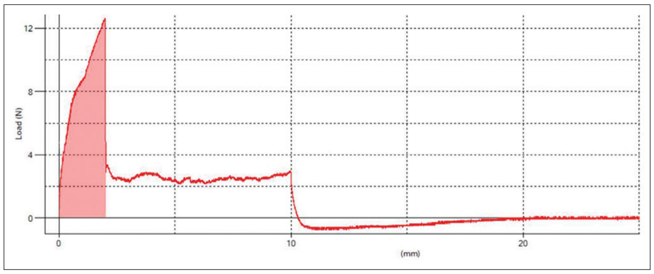

Fig 4. Puncture test curve: the slope of the first peak is crispness (N mm^{-1}), and the area of the red region is toughness (N mm).

RESULTS AND DISCUSSION

Effects of growing location on the fruit texture of olecranon honey peach

The TPA results of olecranon honey peach grown in different locations in China are shown in Fig. 5. The hardness of olecranon honey peach was 17.73 – 100.29 N.

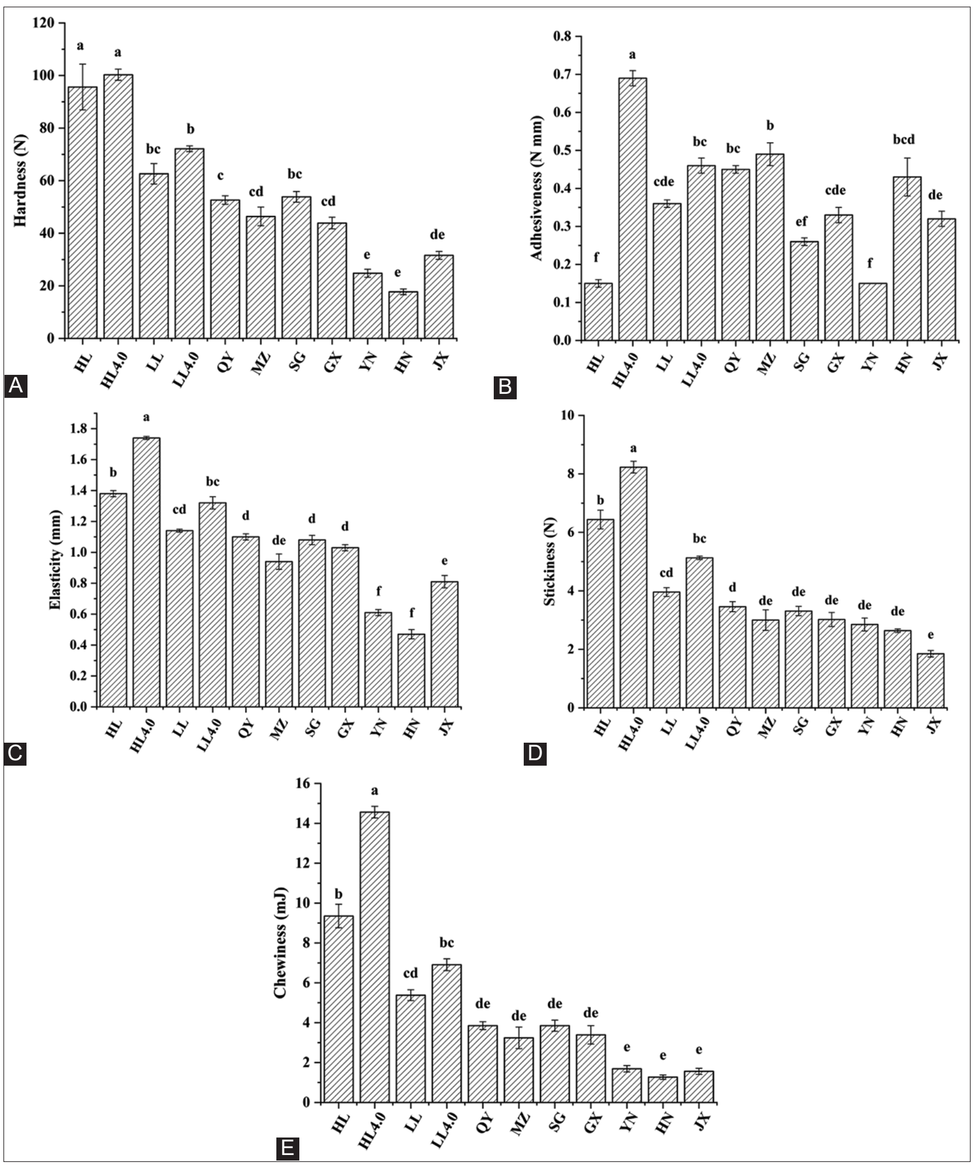

Fig 5. Texture profile analysis of olecranon honey peaches from 11 locations in China. (A) hardness (Ha); (B) adhesiveness (Ad); (C) elasticity (El); (D) stickiness (St) and (E) chewiness (Ch).

The Ha values of HL and HL4.0 were significantly higher than those of olecranon honey peach grown in the other locations (*P* < 0.05) (Fig. 5A). Although the Ha value of HL4.0 (100.29N) and HL (95.62N) were not significantly different (Fig. 5A), indicating that olecranon honey peach planting in High altitude Lianping county more hard than other growing places. Hardness refers to the local resistance to hard objects pressing into its surface. As a whole, the hardness of olecranon honey peach planted in Lianping county is higher than that of other places. The hardness of the olecranon honey peach planted in Guangdong Province is generally higher than that of the olecranon honey peach planted in other provinces. The increase of firmness is beneficial to transportation and storage, and increases the rate of good fruit. Some studies have shown that the fruit is difficult to transport due to its soft texture, resulting in an increase in transportation costs. As some researches showed that planting altitude may influence the hardness of fruits (Charle et al., 2017, Eisenstecken et al., 2019). Although the Ad values of the fruit did not show a particular trend, the Ad value of HL4.0 was significantly higher (*P* < 0.05) than those of olecranon honey peach grown in the other locations (Fig. 5B). Similarly, the El, St, and Ch values of HL4.0 were significantly higher than those of olecranon honey peach grown in the other locations (*P* < 0.05) (Fig. 5C, D and E). Overall, except LL, Lianping County olecranon honey peach had significantly higher Ha, St, El, and Ch values than those grown in the other locations (*P* < 0.05).

There was a significant improvement in Ha, El, St, and Ch (Fig. 5E) of peaches grown in high altitude areas in Lianping County by the common planting method; however, there was a significant decrease in Ad (*P* < 0.05) (Fig. 5B). Similarly, there was an improvement in the Ha, El, Ad, and Ch of olecranon honey peach grown at low and high altitudes in Lianping county using the olecranon honey peach 4.0 technology, indicating that this new planting method can improve fruit texture by increasing the compactness and density of the fruit (Alvarez et al., 2010, Barron et al., 2005). The olecranon honey peach 4.0 technology planting method also significantly improved the Ad of olecranon honey peach grown at low and high altitudes (*P* < 0.05), indicating that this planting method counterbalanced the negative effects of high altitude (Fig. 5B). The improvement in fruit texture of olecranon honey peach from Lianping county can be attributed to favourable climatic and soil conditions, because lianping county planting olecranon honey peach has a long history, and olecranon honey peach mainly terminated in subtropical areas, there are requirements for temperature and humidity. And by applying fermentative fertilizer, it is beneficial to soil microorganism growth and fruit tree nutrition absorption. As shown in Fig. 5, olecranon honey peach grown in different counties (Qingyuan [QY], Meizhou [MZ], and Shaoguan [SG]) had a similar texture, suggesting that the soil, climate, and altitude in these three orchards were similar (Chen and Ye 2007).

The growth pattern of peaches is different from other fruits, such as apple, tomato, and pear (Saladie´et al., 2007, Song et al., 2016, Winisdorffer et al., 2015), peach blossom has only one pistil, so the ovary of a single pistil only has a single carpel (Austin et al., 1998). During ovary development, the two sides of the open carpel begin to close, forming a ventricle, with the edge of the closed carpel becoming an abdominal suture (Liu et al., 2010, Rodrigo and Herrero 2002). The puncture test was conducted on 6 test points of the same sample (Fig. 3) and significance analysis was performed at 6 test points of each sample (Fig. 6 A & B). Through the puncture test on 6 test points of each sample peach, the significance of the data was analysed. The results showed that there was no significant difference in the CUS, CMS, CLS, CU, CM, TUS, TMS, TLS, TU, TM and TL of each sample in the six test points (*P* > 0.05). Therefore, there was no significant difference between the values of crispness and toughness of suture and smooth surface, and there is no significant difference between the values of crispness and toughness of peach upper, middle and lower parts. Indicating that the value between the six test points was similar, and the average value of the six test points can represent the crispness and toughness of the whole peach. Therefore, the average value of 6 directions of each sample represents the crispness and toughness of the whole peach. Crispness refers to the feeling of cracking when the fruit is chewed in the mouth. The TC value of HL4.0 was significantly higher than olecranon honey peach grown in the other locations (*P* < 0.05) (Fig. 6C), indicating that the olecranon honey peach 4.0 technology planting method improved the TC of olecranon honey peach grown in high altitudes. However, olecranon honey peach grown in SG and HL had a significantly higher TT value in all samples (*P* < 0.05) (Fig. 6D).

Chemical measurements and cell structure analysis

Analysis of chemical parameters

The MC, Pe, Pr, Ce, He, Li, TA and SC of olecranon honey peach grown in 11 locations were analysed (Table 3). These chemical parameters are related to fruit and vegetable texture (Batisse et al., 1996, Song et al., 2016, Winisdorffer et al., 2015). The Pe and SC content of SG was significantly higher than olecranon honey peach grown in the other locations (*P* < 0.05). The Pr content of LL 4.0 was significantly higher than olecranon honey peach grown in the other locations (*P* < 0.05). Pectin is abundant in the cell wall of fruit, and combines with cellulose to form a bond between adjacent cells. It closely binds plant tissues together and plays a vital role in maintaining the structure

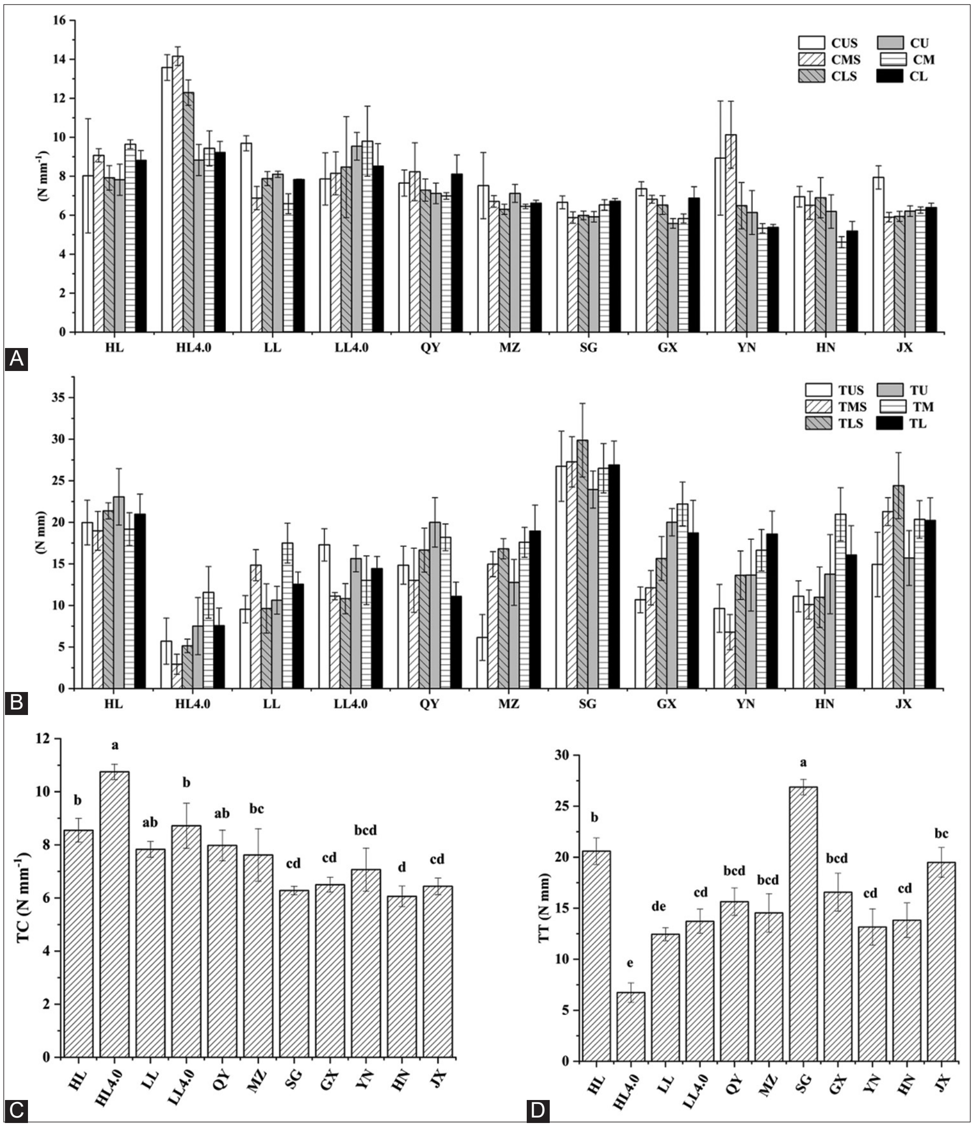

Fig 6. Results of puncture tests of olecranon honey peach from 11 locations in China. (A) crispness of peach at the suture and the smooth surface, including CUS, CMS, CLS, CU, CM, CL; (B) toughness of peach at the suture and the smooth surface, including TUS, TMS, TLS, TU, TM, TL (Fig. 2). (C) total crispness of the hard peach (TC); (D) total toughness of the hard peach (TT).

Table 3: Effects of growing location on the chemical parameters of the olecranon honey peach

Cultivar	MC (g/100g)	Pe (g/kg)	Pr (g/kg)	Ce (g/100g)	He (g/100g)	Li (g/100g)	TA (%)	SC（BRIX%）
HL	83.20^{aa}±3.39^{b}	3.46^{d}±0.35	0.89^{b}±0.06	4.70^{a}±0.11	0.70^{bc}±0.12	0.50^{a}±0.07	0.36^{bc}±0.03	16.84^{bc}±0.38
HL4.0	85.00^{ab}±2.18	3.61^{de}±0.09	0.41^{cde}±0.06	1.60^{g}±0.07	0.80^{ab}±0.16	0.40^{ab}±0.12	0.21^{d}±0.10	16.23^{cd}±0.58
LL	85.90^{ab}±1.52	3.59^{de}±0.13	0.54^{d}±0.19	1.20^{h}±0.25	0.90^{a}±0.16	0.30^{bc}±0.12	0.28^{cd}±0.08	15.41^{de}±0.46
LL4.0	87.90^{a}±1.97	3.75^{cd}±0.14	1.16^{a}±0.26	2.40^{e}±0.25	0.70^{bc}±0.07	0.30^{bc}±0.07	0.34^{bc}±0.09	16.36^{cd}±0.38
QY	86.60^{a}±1.51	2.02^{g}±0.23	0.43^{cd}±0.16	3.40^{c}±0.17	0.70^{bc}±0.07	0.30^{bc}±0.07	0.36^{bc}±0.15	16.53^{bc}±0.37
MZ	86.10^{a}±2.05	3.86^{c}±0.14	0.52^{d}±0.07	3.00^{d}±0.32	0.80^{ab}±0.16	0.20^{c}±0.07	0.34^{cbc}±0.08	15.11^{e}±0.24
SG	85.30^{ab}±1.16	4.77^{a}±0.12	0.38^{cde}±0.05	4.70^{a}±0.16	0.60^{cd}±0.07	0.30^{bc}±0.07	0.44^{ab}±0.08	18.80^{a}±0.61
GX	87.90^{a}±2.14	4.46^{b}±0.15	0.76^{bc}±0.09	2.20^{e}±0.12	0.50^{d}±0.07	0.50^{a}±0.07	0.33^{bc}±0.08	16.16^{cd}±0.44
YN	85.90^{ab}±1.68	3.74^{cd}±0.12	0.72^{c}±0.14	3.90^{b}±0.22	0.50^{d}±0.10	0.40^{ab}±0.07	0.54^{a}±0.04	17.45^{b}±0.74
HN	85.40^{ab}±1.64	2.29f±0.07	0.36^{de}±0.04	1.90f±0.16	0.30^{e}±0.07	0.30^{bc}±0.07	0.35^{bc}±0.05	16.97^{bc}±0.54
JX	86.40^{a}±1.27	2.01^{g}±0.14	0.25^{e}±0.05	1.20^{h}±0.25	0.70^{bc}±0.12	0.40^{ab}±0.07	0.35^{bc}±0.10	16.54^{bc}±0.52

Values are mean ± standard error.
[a]Different letter in the same column represent significant differences between means ($P < 0.05$) by Duncan's multiple-range test.
[b]indicates standard error.

and hardness of plants. Protopectin exists in immature fruit. As the fruit matures, pectin is hydrolyzed by pectinase and organic acid(Poles et al., 2020). These two substances mainly exist in the plant cell wall and play a supporting role. It can be seen from Table 3 that the pectin content of four samples of olecranon honey peach in Lianping area is high, and the pectin content of peaches planted with olecranon honey peach 4.0 technology is significantly higher ($P < 0.05$). The pectin content of MZ and QY in Guangdong Province, and JX and YN outside Guangdong Province is second, and the pectin content of hard flesh peach is higher than that of soft peach on the whole. The content of protopectin in fruit development stage is high. With the ripening of fruit, protopectin will be gradually transformed into pectin under the catalysis of enzyme, and the fruit will become soft. Therefore, the original pectin is also an important chemical index to judge the quality of olecranon honey peach. Table 3 shows that in Lianping county, the change of original pectin content is similar to that of pectin, and the olecranon honey peach 4.0 technology can improve the original pectin content. For other regions, the original pectin content of samples with high pectin content is not necessarily high, which may be caused by the high content of methyl pectinate and pectinic acid Both cellulose and hemicellulose are the main skeleton of plant cell wall, which makes the cell wall structure stable Additionally, the Ce contents of HL and SG were significantly higher than in peaches grown in the other locations ($P < 0.05$), whereas peaches grown in HL4.0 and LL had significantly lower Ce content ($P < 0.05$). LL had the highest He content ($P < 0.05$), whereas HL and GX had the highest Li content ($P < 0.05$).

The Pearson's correlation of chemical parameters showed that, except MC and SC, which was significantly correlated with TA ($P < 0.05$, r = 0.55), the chemical parameters of fruits were not significantly correlated (Table 4); showing that there was almost no correlation and collinearity between the chemical parameters.

Table 4: Pearson's correlation of chemical parameters in the olecranon honey peach

	MC	Pe	Pr	Ce	He	Li	TA	OA	SC
MC	1								
Pe	-0.33	1							
Pr	-0.04	0.48	1						
Ce	-0.39	0.28	0.25	1					
He	-0.11	0.22	0.10	-0.03	1				
Li	-0.48	0.26	0.30	0.24	0.04	1			
TA	0.55*	-0.20	-0.05	0.16	-0.47	-0.43	1		
OA	-0.41	0.19	0.29	0.30	-0.24	0.53	-0.06	1	
SC	-0.27	0.17	-0.12	0.60	-0.53	0.18	0.64*	0.12	1

Correlation coefficient (r), ranging from 0.80–1.00, 0.60–0.80, 0.40–0.60, and 0.20–0.40 indicates that the variables are very strongly, strongly, moderately, and weakly correlated, respectively. R > 0 indicates a positive correlation, whereas r < 0 indicates a negative correlation.
*Indicates that the correlation was significant at 0.05 ($P < 0.05$) by Duncan's multiple-range test.

Cell wall structure of olecranon honey peach

The ultrastructure of olecranon honey peach was shown in Fig. 7. The cell walls exhibited uniform thickness and were orderly arranged, and the structure of the middle lamella was "light and dark", indicating that the cell structure was compact. On the whole, the cell wall of peach from Lianping county (Fig.7 A-D) thicker than other planting places. Furthermore, 4.0 planting technology can increase the thickness of the cell wall. Peaches cell wall which from Guangdong province (Fig.7 E-G) was thicker than other provinces (Fig.7 F-K). The main components of the cell wall are pectin and cellulose, so the stable structure of the cell wall can increase the brittleness of the fruit. The structure of the cell wall is the key factor affecting the texture. The olecranon honey peach 4.0 planting technology can increase the pectin and cellulose content of the olecranon honey peach, and increase the cell wall thickness. Therefore, the olecranon honey peach planted with the olecranon honey peach 4.0 technology has higher brittleness and more crisp taste. Some studies have shown that organic planting can improve the photosynthetic performance and growth status of crops, increase the speed of organic transformation, improve the soil environment, enhance soil enzyme activity, and promote the absorption of soil elements by plants(Cantin and Gracia 2022). The characteristics of the planting technology of olecranon honey peach 4.0 is to use food by-products such as fish offal and fish bones for microbial fermentation, so it can increase the content of soil nitrogen and calcium ions, Plants absorb calcium ion to promote the formation of cytoskeleton, and also maintain the stability of cell wall and cell membrane. Therefore, it can promote the stability of cell wall and cell wall of olecranon honey peach, thus increasing the quality of fruit. This conclusion was consistent with the result of the peach crispness, which was in agreement with previous studies (Ma et al., 2020, Nieto et al., 2013).

Relationship between texture and chemical parameters of olecranon honey peach

Correlation analysis

The results of the correlation analysis of texture and chemical parameters of olecranon honey peach are shown in Table 5. All texture parameters, except Ad were significantly negatively correlated with MC (r > 0.60; $P < 0.05$, <0.001), which was consistent with the findings of Kita Kita et al. (2004) and Nieto Nieto et al. (2013). The negative correlation indicates that the higher the MC, the lower the values of the texture parameters. Pectin is a major factor affecting the texture of fruit and vegetables. In the present study, Ha and El were significantly correlated (r = 0.54 and 0.54, respectively; $P < 0.05$) with pectin

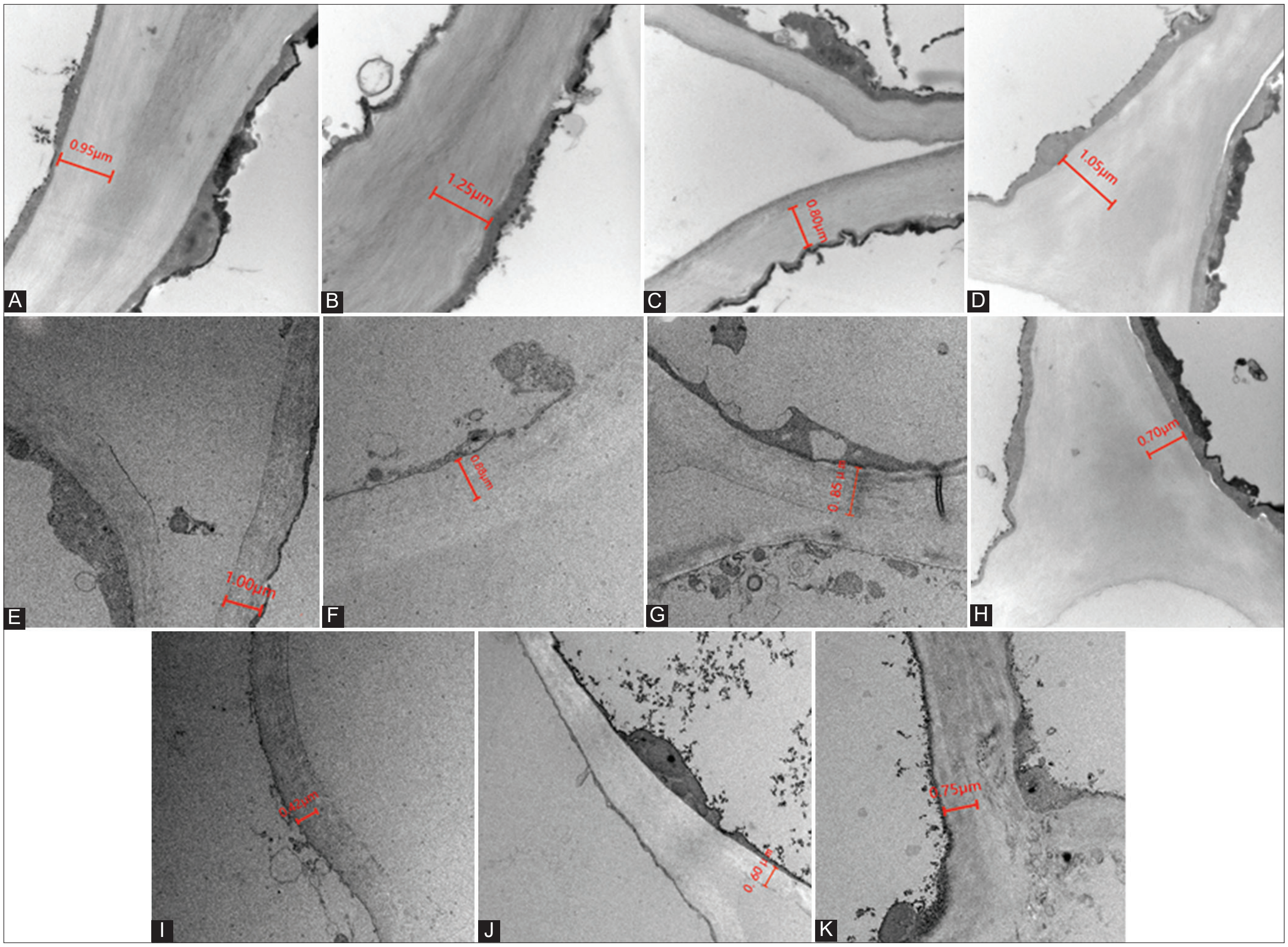

Fig 7. Transmission electron microscopy (TEM) of olecranon honey peach tissue. (A) HL; (B) HL4.0; (C) LL; (D) LL4.0; (E) QY; (F) MZ; (G) SG; (H) GX; (I) YN; (J) HN; (K) JX. The red width indicates the thickness of the peach cell wall.

Table 5: Pearson's correlation coefficients between texture and chemical parameters of the olecranon honey peach

	MC	Pe	Pr	Ce	He	Li	TA	OA	SC
Ha	-0.69**	0.53*	0.49	0.28	0.32	0.47	-0.44	0.42	-0.41
Ad	0.12	0.15	-0.04	-0.40	0.25	-0.24	-0.20	0.12	0.37
El	-0.61*	0.54*	0.41	0.13	0.18	0.37	-0.37	0.35	-0.01
St	-0.70**	0.49	0.43	0.20	0.24	0.48	-0.50	0.49	-3.45
Ch	-0.59*	0.44	0.37	0.13	0.31	0.44	-0.47	0.43	-0.02
TC	-0.65*	0.52	0.43	0.15	0.45	0.43	-0.74**	0.29	-0.01
TT	-0.66*	0.52	-0.15	0.22	0.28	0.38	-0.54*	0.08	-0.01

Correlation coefficient (r) from 0.80–1.00, 0.60–0.80, 0.40–0.60, and 0.20–0.40 indicates that the variables are very strongly, strongly, moderately, and weakly correlated, respectively. r > 0 indicates a positive correlation, and r < 0 indicates a negative correlation.
*Indicates the correlation was significant at $P < 0.05$
**Indicates the correlation was highly significant at $P < 0.001$.

content of olecranon honey peach, indicating that the higher the pectin content, the higher the Ha and El of the peach. This was in agreement with the results of Song Song et al. (2016). TC and TT were significantly negatively correlated (r = -0.74, -0.54, respectively; $P < 0.05$) with TA, indicating that the higher the TA value, the lower the TC and TT, which was consistent with Hoehn Hoehn et al. (2003). However, texture parameters were not correlated with protopectin, cellulose, hemicellulose, lignin, orchard altitude and sugar content ($P > 0.05$). However, some studies have shown that there is a correlation between these parameters (Abu-Goukh and Bashir 2003, Song et al., 2016). This discrepancy in results can be attributed to the duration of this study, as only a year's data was analysed.

PCA of texture and chemical parameters of olecranon honey peach

The PCA is an effective way of visualising the distribution of the different texture and chemical parameters of olecranon honey peach grown at 11 different locations. PCA is often used to compare differences between samples, and to identify which variables contribute the most (Kim et al., 2012). The PCA showed that the texture parameters (Hd, Ad, El, St, Ch, TC, and TT) were clustered in PC1, with a cumulative contribution rate of 37.3% (Fig. 8). However, the chemical parameters (MC, Pe, Pr, Ce, He, Li, TA, SC and OA) were clustered in PC2, with a cumulative contribution rate of 23.3%6. The blue arrow in Fig. 8 represents the loading plot of 16 components. To identify the main contributors to PC1 and PC2, the load factors of PC1 and PC2 were compared. The relative contributions of PC1 were Ha, El, St, Ch, and TC, all of which were positively correlated with the peach. The main load factors of PC2 were Ce, TA, and SC, all of which were positively correlated with the peach. Therefore, PC1 was related to the texture parameters, whereas PC2 was related to the chemical properties. This showed that the larger the abscissa, the larger the proportion of physical and mechanical texture, and vice versa. On the positive PC1, HL4.0 was located near TT, which means HL4.0 has an advantage over the other olecranon honey peach, in terms of TT (Fig. 8). This is consistent with the results in Fig. 5A. The loading rate of HL in PC2 was significantly higher than the other samples, indicating that HL was better in Pe and TA, which is consistent with the results in Table 3. olecranon honey peach grown in Lianping County was positively correlated with texture parameters (Ha, Ad, El, St, Ch, and TC); however, olecranon honey peach grown in the other locations (except HL, HL4.0, LL, LL4.0, and YN) were negatively correlated with all the texture parameters except TT, which suggested that olecranon honey peach planted in Lianping County had a positive correlation with texture.

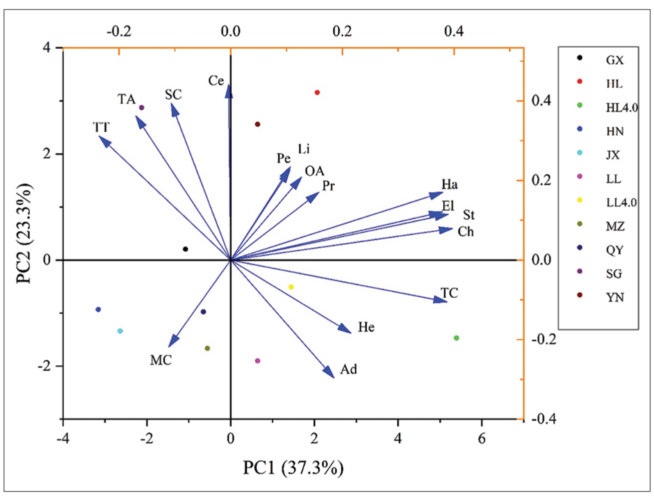

Fig 8. PCA of the texture and chemical parameters of olecranon honey peach grown in 11 locations across China (Table 1).

Prediction models of texture parameters of olecranon honey peach

Previous studies are limited to the correlation between peach parameters; no attempt to develop an effective model to predict the texture quality of olecranon honey peach has been made. This research established a model to predict the texture quality of olecranon honey peach, based on chemical parameters. MLR was used to process the chemical and organisational structure parameter data to estimate the best predictive model for each chemical and texture parameter (Table 6). The results were analysed using correlation analysis. The MC, Pe. and TA were selected for linear fitting because they had the highest correlation with texture parameters of olecranon honey peach. The coefficient of determination (R^2), and root mean square error (RMSE) for the parameters are presented in Table 6. The values of Ha, El, St, Ch, TC, and TT were determined based on selected chemical parameters. Ha had the highest degree of fit (R^2 = 0.328) and TT had the smallest degree of fit (R^2 = 0.073). The RMSE is the square root of the ratio of the square of the deviation between the predicted value and the true value to the number of observations, and the standard error reflects the precision of the measurement. There were two degrees of freedom for HA, EL, TC, and TT, and one degree of freedom for the other texture parameters. The R^2 values of Ch, TC, and TT were the lowest three parameters.

To further examine the relationship between the texture and chemical parameters of olecranon honey peach, a partial least squares regression verification was established, based on MC, Pe, and TA for texture parameters (Table 7). The results showed that the prediction results for Ha and El were relatively good, with R_c^2 values of 0.308 and 0.281, respectively, and RMSEC values of 17.508 and 0.260, respectively. The results were similar to those of the prediction model, and the differences in R_p^2 were 0.012 and 0.004, respectively, while that of the RMSEP were 0.274 and 0.058, indicating that MC and Pe were effective parameters for determining Ha and El. The prediction results for TC and TT were poor, with R_c^2 values of 0.092 and 0.037, respectively, indicating that they had a low correlation with MC and TA, and may not be able to predict the value of TC and TT accurately.

Table 6: Stepwise multi-linear regression and R^2 estimated for each texture and chemical parameter

Parameters (Y)	Equation	R^2	*P*-value	RMSE
Ha	Y=395.291-4.382MC+10.247Pe	0.328	< 0.001	25.509
El	Y=4.650+10.767MC+15.418Pe	0.302	< 0.001	0.401
St	Y=35.988-1.376MC	0.205	< 0.001	2.016
Ch	Y=53.036-0.563MC	0.132	< 0.001	3.933
TC	Y=21.409-0.140MC - 5.047TA	0.125	< 0.001	1.635
TT	Y=31.817-0.247MC+14.591TA	0.073	< 0.001	6.381

R^2: determination coefficient, RMSE: root mean square error.

Table 7: Model results of peach texture and chemical properties, based on partial least square method.

Parameters	Calibration		Validation	
	R_c^2	RMSEC	R_p^2	RMSEP
Ha	0.308	17.508	0.296	17.782
El	0.281	0.260	0.277	0.318
St	0.193	1.015	0.187	1.021
Ch	0.119	1.521	0.107	1.132
TC	0.092	0.607	0.084	0.701
TT	0.037	1.753	0.033	1.884

Rc^2: coefficient of determination after calibration; RMSEC: root mean square error after calibration Rp^2: coefficient of determination after validation; RMSEP: root mean square error after validation.

CONCLUSION

This study shows that the texture and chemical properties of olecranon honey peach are significantly affected by growing location, olecranon honey peach planting in Lianping county and using 4.0 planting technology had better texture than other samples. Additionally, there is no significant difference in the value of crispness and toughness between peach suture and smooth surface, so the sampling locations did not affect the determination. The texture of olecranon honey peach is related to pectin, cellulose and cell wall thickness. The higher the content of pectin and cellulose in the fruit, the thicker the cell wall, and the more crisp the fruit. By applying biological fermentation fertilizer containing high calcium and protein, olecranon honey peach 4.0 technology can increase the texture of the fruit, improve the hardness of the fruit, increase its crispness, and facilitate the circulation of the fruit. A predictive model was developed for determining the texture of olecranon honey peach, based on chemical properties.

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Authors' contributions

Yuanxin Qiu: Investigation, Formal analysis, Writing – Review and Editing; Kaiqi Zhu: Writing – Original Draft, Chemical and Data analysis; Jianliang Liu: Funding acquisition; Guide the planting of samples. Hairu Yuan, Cungang Li, and Zexiong Zhang: Data processing and Image editing.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical guidelines

Ethics approval was not required for this research.

Conflict of interest

All the authors have no conflict of interest to declare.

Informed consent

Written informed consent was obtained from all study participants.

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