Establishment of a Determination Method for Fruit Texture in Chieh-qua Using Texture Analyzer

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Abstract [**Objectives**] This study was conducted to establish a quantitative assessment method for the textural quality of chieh-qua fruit. [**Methods**] Using two modes of a texture analyzer, namely TPA (texture profile analysis) and puncture, the index data of the fruit were obtained by setting different trigger forces, deformation levels, test speeds, as well as puncture speeds and puncture depths. The data included TPA hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, resilience, as well as skin hardness, skin toughness, flesh hardness, fracturability, and compactness. [**Results**] Different deformation levels had a significant impact on all parameters. Hardness, adhesiveness, gumminess and chewiness showed a trend of first increasing and then decreasing with the deformation level increasing. When the deformation level was 30%, the adhesiveness, gumminess and chewiness reached their maximum values. When the deformation level was 50%, TPA hardness reached its maximum. When the compression speed was 3 mm/s, the measured values of TPA hardness, adhesiveness, chewiness, and resilience were at their maximums. The skin hardness varied significantly under different trigger forces. When the trigger force was 15 g, the skin hardness reached a maximum value of 944.63 g, and the skin toughness, flesh hardness, fracturability, and compactness also reach their maximum values respectively. When the puncture depth was 12 mm, the flesh hardness and skin toughness reached their maximums of 682.51 g and 1.82 mm, respectively. In the TPA mode, the flesh hardness of chieh-qua showed an extremely significant negative correlation with springiness, cohesiveness, and resilience ($P < 0.01$). The fruit fracturability detected by puncture had an extremely significant positive correlation with compactness ($P < 0.01$). [**Conclusions**] The evaluation method for measuring chieh-qua texture by combining TPA and the puncture mode could accurately and quantitatively reflect the differences in the flesh texture quality of chieh-qua. The optimal parameters for texture measurement of chieh-qua fruit were determined as a 15 g trigger force with 50% deformation and a 3 mm/s compression speed in TPA mode, and a 15 g trigger force with a 12 mm puncture depth in puncture mode. Puncture speed was found to have no significant effect on the texture indices of chieh-qua.

Key words Chieh-qua; Texture analyzer; Texture quality; Determination method

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Chieh-qua (*Benincasa hispida* Cogn. var. *chieh-qua*), also known as Maogua or Beigua, is a variant of Benincasa in the Cucurbitaceae family. Originating in China, it is a common vegetable in southern China valued for both culinary and medicinal applications. Its appearance resembles that of a small wax gourd, but its flesh is denser and offers a crisper, sweeter, and more succulent texture. It can be consumed fresh and is suitable for various cooking methods such as stir-frying, stewing, stuffing, and soup-making. Both tender and mature fruits are edible, contributing to its widespread consumption[1]. Texture quality, as a crucial indicator for evaluating the fruit quality and processing suitability of chieh-qua, is closely related to product freshness and edibility, thereby directly influencing consumer preference, shelf life, and the final quality of processed products[2]. The ideal texture of chieh-qua is typically characterized by crisp and tender flesh, moderate firmness, and abundant juiciness. However, factors such as postharvest physiological changes, storage conditions and processing treatments can easily lead to texture deterioration, including softening, browning, or water loss and wilting, which severely compromise its marketability[3]. Therefore, the scientific and accurate evaluation of chieh-qua texture quality is of great significance for breeding good varieties, optimizing postharvest treatment techniques, improving storage and preservation effects, and developing well-suited processed products.

Currently, methods for determining the texture of fruits and vegetables mainly fall into two categories: sensory evaluation and instrumental analysis. Sensory evaluation is susceptible to individual differences and environmental factors, presenting limitations such as strong subjectivity, poor reproducibility, and difficulty in standardization. In contrast, instrumental analysis, particularly the application of texture analyzers, has become the mainstream method for texture measurement in fruits and vegetables due to its advantages of objectivity, quantifiability, and high reproducibility[4–5]. The most commonly used testing modes for texture analysis of fruits and vegetables using a texture analyzer include texture profile analysis (TPA) and puncture tests. The fundamental principle involves compressing or puncturing a sample with a specific probe at a preset speed to obtain mechanical parameter curves and quantitative data that reflect the texture characteristics of the sample[6]. In recent years, texture analyzers have been widely applied in texture quality analysis of fruits and vegetables such as apples[7], kiwifruits[8], watermelons[9], melons[10], Chinese cabbages[11], chestnuts[12], and potatoes[13]. Han *et al.*[14] used the TPA method to determine the textural properties of three types of fresh lotus roots and found that the high hardness of fresh lotus

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roots was related to their high starch content. Additionally, gumminess was positively correlated with hardness, and could improve the texture of lotus roots after cooking, while chewiness, as an important parameter reflecting the texture of fresh lotus roots, can negatively affect the mouthfeel when excessively high. Pan *et al.* [4] used the puncture method on a texture analyzer to measure the texture parameters of Sanhua plum fruits. The results indicated that peel strength, peel rupture distance, and peel toughness can serve as key parameters for the quantitative evaluation of the texture characteristics of Sanhua plum fruits. Wang *et al.* [15] carried out texture analyzer TPA and puncture tests on 14 pear cultivars. The results showed that most TPA parameters of pear flesh were significantly positively correlated with puncture test parameters, and flesh hardness, fracture force, and frangibility were identified as important parameters influencing the texture of pear flesh.

In the cultivation and production of chieh-qua, there is a rich diversity of variety resources. As a key quality trait, the texture of the flesh and its correlation mechanism with sensory quality remain unclear. Even with identical nutritional components, variations in texture can lead to differences in taste perception. Consequently, different texture types influence consumer acceptance to varying degrees[16]. However, there are currently no reported studies on the evaluation and analysis of the texture quality of chieh-qua, and a quantifiable method for detecting and assessing the texture quality of chieh-qua remains unavailable. In this study, using texture profile analysis (TPA) and puncture testing of a texture analyzer, a standardized method for evaluating the flesh texture of chieh-qua was developed by optimizing parameters including trigger force, deformation, compression speed, puncture speed, and puncture depth. This study will provide a basis for the comprehensive assessment of chieh-qua fruit texture.

Materials and Methods

Experimental materials

Chieh-qua: The tested variety was 'c24-84', provided by the chieh-qua breeding team of Institute of Horticulture, Shanghai Academy of Agricultural Sciences. The samples were harvested in December 2024 from the Zhuanghang Experimental Station of Shanghai Academy of Agricultural Sciences. The fruits were selected based on uniform shape, consistent maturity, and the absence of pests, diseases, mechanical damage, or rot.

Experimental Instruments

Texture analyzer: TA-XT. Plus C model, manufactured by Stable Micro System, United Kingdom.

Experimental methods

Following the method of Yang *et al.* [17], chieh-qua fruit was transversely cut in half at the midpoint. From the equatorial region of the flesh, 2 cm thick slices were taken. Using a 2 cm diameter corer, 10 cylindrical samples were extracted from each slice (Fig. 1) for texture analyzer testing, with 5 samples designated for TPA (texture profile analysis) testing and the remaining 5 for puncture testing.

Fig. 1 Examples of chieh-qua sampling

TPA texture analysis Parameters including TPA hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience were measured in TPA mode. A cylindrical probe (P/50) with a diameter of 50 mm was used for the tests. The TPA texture characteristic curve of the chieh-qua fruit is shown in Fig. 2. The TPA parameters were defined with reference to the methods of Bianchi *et al.* [18] and Pan *et al.* [10]. The TPA texture test indicators for the chieh-qua fruit were calculated from the texture characteristic curve using the texture analyzer software.

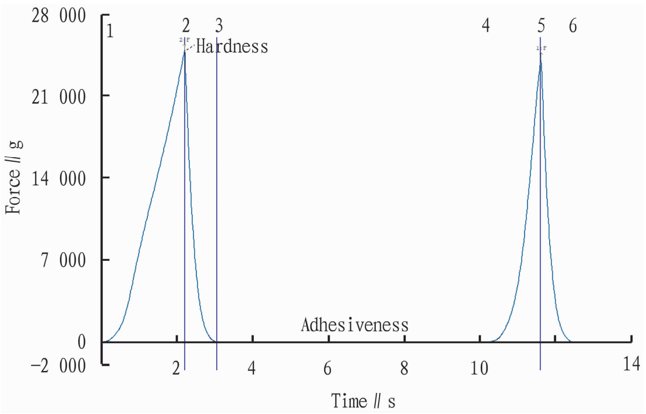

Fig. 2 The TPA illustration curve of texture character of chieh-qua fruit

Comparison of different trigger forces: During testing, the fruit was placed at the center of the texture analyzer's loading platform. To evaluate the effect of trigger force, the changes in hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience were measured by setting the trigger force to 5, 10, 15, 20, and 25 g, respectively. All other parameters were held constant: pre-compression speed at 2 mm/s, test speed at 3 mm/s, post-compression retraction speed at 2 mm/s, sample deformation at 30%, and a 5 s interval between compressions. Each treatment was replicated using five fruit samples for testing.

Comparison of different deformation levels: The changes in the seven indicators including hardness and adhesiveness under different deformation levels were obtained by setting the deformation level to 10%, 30%, 50%, and 70%, respectively. All other parameters were kept constant: trigger force of 15 g, pre-compression speed at 2 mm/s, test speed at 3 mm/s, post-compression retraction speed at 2 mm/s, and a 5 s interval between two compressions. Each treatment was replicated using five fruit samples for testing.

Comparison of different test speeds: The changes in the seven indicators including hardness, adhesiveness under different test speeds were measured by setting the test speed to 1, 2, 3, 4, and 5 mm/s, respectively. Other parameters were kept constant: trigger force of 15 g, sample deformation at 30%, pre-compression speed at 2 mm/s, post-compression retraction speed at 2 mm/s, and a 5 s interval between two compressions. Each treatment was replicated using five fruit samples for testing.

Puncture texture analysis The puncture mode measured indicators including skin hardness, skin toughness, flesh hardness, fracturability, and compactness. A P2 needle-shaped probe was used, and the puncture was performed at the center of the fruit sample. The characteristic curve of the puncture texture detection for chieh-qua flesh is shown in Fig. 3. The force value at the first peak is defined as the skin hardness (g), and the distance from when the probe contacts the skin to when it punctures through is defined as skin toughness (mm)[19]. The linear distance between anchors 1 and 2 on the puncture characteristic curve is defined as fracturability (g·s)[12,20]. The area between anchors 3 and 4 on the characteristic curve is defined as compactness (g·s)[12,21].

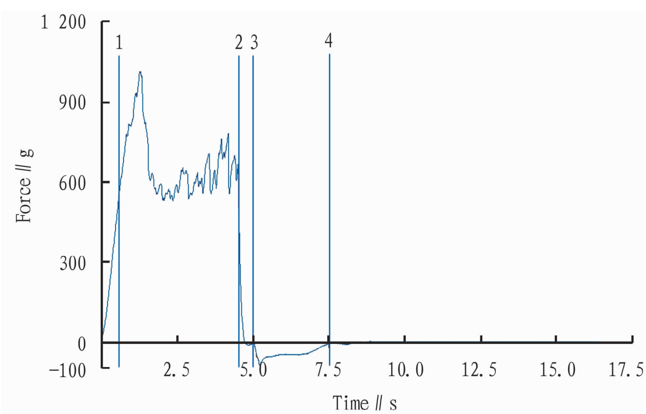

Fig. 3 The illustration curve of puncture test of chieh-qua fruit

Using different trigger forces (5, 10, 15, 20, 25 g), puncture speeds (1, 2, 3, 4, 5 mm/s), and puncture depths (3, 6, 9, 12, 15mm) as single-factor parameters, with a pre-test speed of 2 mm/s and a post-test speed of 2 mm/s, tests were conducted in the TPA mode. The analysis examined the texture changes of chieh-qua under following conditions: constant puncture speed (2 mm/s) and puncture depth (12 mm) with varying trigger forces, constant trigger force (15 g) and puncture depth (12 mm) with varying puncture speeds, and constant trigger force (15 g) and puncture speed (2 mm/s) with varying puncture depths. Five samples were selected for testing under each treatment condition.

Data Analysis

Data collection and organization were performed using Excel 2016. Significance and correlation analyses of the data were conducted using IBM SPSS Statistics 26 software, with a significance level set at 0.05.

Results and Analysis

Comparison of chieh-qua texture quality under different TPA testing parameters

As shown in Table 1, the trigger force did not have a significant impact on texture attributes such as TPA hardness, but higher trigger forces resulted in increased hardness values. Significant differences in chewiness were observed under different trigger forces. When the trigger force was set to 15 g, chewiness was the lowest. Chewiness, defined as the work required to masticate solid food to a swallowable state, is a key objective indicator for evaluating texture and edible quality. The combined measurement results indicate that a trigger force of 15 g in TPA testing for chieh-qua effectively reflected texture differences. Different deformation levels had significant effects on all TPA indicators, including hardness, adhesiveness, springiness, and cohesiveness. Hardness, adhesiveness, gumminess and chewiness initially increased and then decreased as the deformation level rose. At a deformation level of 30%, adhesiveness, gumminess and chewiness reached their maximum values, which were significantly higher than those observed at 10%, 50%, and 70% deformation levels. When the deformation level reached 50%, TPA hardness was the highest. However, as the deformation level increased, springiness, cohesiveness and resilience significantly decreased. These attributes are directly related to the structural integrity of the sample. During TPA indicator measurements, it is essential not only to maintain the integrity of the fruit, but also to achieve the maximum hardness value. When the deformation level is small, the hardness is also low, making it impossible to determine the maximum hardness value of the fruit. However, when the deformation level exceeds a certain critical point, irreversible damage occurs to the sample's microstructure. At a deformation level of 70%, cohesiveness and resilience sharply declined. Therefore, a deformation level of 50% was considered more suitable for texture measurement in chieh-qua. Different compression speeds did not have a significant impact on TPA hardness, but they substantially affected cohesiveness, gumminess, chewiness, and resilience. As the compression speed increased, gumminess, chewiness and resilience generally showed an initial rise followed by a decline. When the compression speed was set to 3 mm/s, the TPA hardness, gumminess, chewiness and resilience of the chieh-qua fruit reached their maximum values.

Comparison of chieh-qua texture quality under different puncture testing parameters

As shown in Table 2, different trigger forces had no significant effect on texture indicators such as skin toughness, flesh hardness, fracturability, and compactness. However, skin hardness showed significant differences under varying trigger forces. When the trigger force was set to 15 g, skin hardness reached its maximum value of 944.63 g, while skin toughness, flesh hardness, fracturability and compactness also achieved their respective maximum values. Different puncture speeds had no great impact on various texture quality indicators. No significant differences were observed in skin hardness, skin toughness, flesh hardness, fracturability, or compactness. When the puncture speed was set to 4 mm/s, the flesh hardness, fracturability and compactness of chieh-qua reached their maximum values. Under varying trigger forces and puncture speeds, the patterns of change in flesh hardness and fracturability were consistent, showing an initial increase followed by a decline, with maximum values achieved at a trigger force of 15 g and a puncture speed of 4 mm/s. Different puncture depths did not have a significant impact on hardness, which might be attributed to relatively uniform texture of chieh-qua flesh. However, puncture depth significantly affected skin toughness, fracturability and compactness. As the puncture depth increased, the measured values of fracturability and compactness consistently rose. When the puncture depth was set to 12 mm, both skin hardness and skin toughness reached their maximum values, measuring 682.51 g and 1.82 mm, respectively. Fracturability and compactness showed a consistent increasing trend with greater puncture depths. At a puncture depth of 15 mm, the measured fracturability reached its maximum value of 4 037.67 g · s, and compactness peaked at 204.04 g · s. Both the two were significantly higher than values obtained at other puncture depths. Based on a comprehensive analysis, at a puncture depth of 12 mm, skin toughness was significantly greater than values in other treatments, and fracturability and compactness also showed clear differences from other conditions. It indicated that a puncture depth of 12 mm effectively reflected texture variations in chieh-qua.

Table1 Results of chieh-qua texture determination under different parameter conditions via TPA test

Detection parameter	Level	Hardness g	Adhesiveness g · s	Springiness	Cohesiveness	Gumminess g	Chewiness g	Resilience
Trigger force//g	5	19 864.93 ± 2 840.89 a	42.52 ± 16.16 a	0.62 ± 0.01 a	0.49 ± 0.02 a	11 127.99 ± 1 565.93 a	6 932.13 ± 1 117.12 ab	0.26 ± 0.01 a
	10	20 101.47 ± 2 915.09 a	41.67 ± 32.26 a	0.61 ± 0.02 a	0.51 ± 0.03 a	10 246.53 ± 1 577.11 a	6 292.78 ± 869.05 ab	0.25 ± 0.01 a
	15	20 918.85 ± 3 756.55 a	34.81 ± 6.92 a	0.61 ± 0.01 a	0.43 ± 0.11 a	8 665.61 ± 1 065.04 a	5 276.47 ± 693.75 b	0.22 ± 0.07 a
	20	22 731.45 ± 3 129.35 a	33.41 ± 15.06 a	0.61 ± 0.02 a	0.50 ± 0.02 a	11 377.20 ± 1 839.84 a	6 951.71 ± 1 016.96 ab	0.24 ± 0.01 a
	25	23 425.64 ± 2 625.70 a	20.74 ± 10.21 a	0.63 ± 0.02 a	0.49 ± 0.01 a	11 396.46 ± 1 223.13 a	7 147.27 ± 916.80 a	0.23 ± 0.01 a
Deformation//%	10	3 811.29 ± 238.65 c	5.33 ± 5.20 a	0.86 ± 0.03 a	0.81 ± 0.04 a	3 072.36 ± 259.37 c	2 643.37 ± 292.73 b	0.64 ± 0.06 a
	30	21 865.11 ± 1 883.67 b	30.22 ± 12.79 c	0.66 ± 0.01 b	0.48 ± 0.01 b	10 560.12 ± 991.95 a	7 012.08 ± 583.25 a	0.25 ± 0.01 b
	50	27 635.08 ± 1 839.66 a	21.62 ± 2.79 bc	0.48 ± 0.02 c	0.23 ± 0.02 c	6 365.07 ± 793.19 b	3 060.57 ± 464.79 b	0.12 ± 0.01 c
	70	25 967.37 ± 3 277.98 a	13.38 ± 8.41 ab	0.43 ± 0.07 c	0.10 ± 0.03 d	2 555.30 ± 1 097.40 c	1 069.32 ± 397.13 c	0.04 ± 0.01 d
Compression speed//mm/s	1	18 311.23 ± 2 225.16 a	62.13 ± 8.92 b	0.65 ± 0.03 a	0.52 ± 0.02 a	7 930.56 ± 1 454.81 b	4 898.58 ± 1 256.10 b	0.22 ± 0.01 b
	2	22 460.85 ± 4 111.47 a	32.43 ± 12.83 a	0.64 ± 0.02 a	0.5 ± 0.04 ab	11 201.70 ± 2 176.96 ab	7 200.78 ± 1 341.05 ab	0.24 ± 0.01ab
	3	23 674.42 ± 1 184.74 a	22.44 ± 10.52 a	0.62 ± 0.03 a	0.42 ± 0.07 b	12 175.89 ± 1 344.06 a	7 923.74 ± 960.31 a	0.27 ± 0.05 a
	4	21 687.74 ± 3 253.16 a	22.66 ± 14.75 a	0.64 ± 0.02 a	0.52 ± 0.03 a	11 321.24 ± 1 459.88 ab	7 288.32 ± 974.72 a	0.27 ± 0.01 a
	5	19 212.47 ± 3 436.44 a	26.82 ± 7.87 a	0.62 ± 0.01 a	0.49 ± 0.04 ab	9 506.79 ± 2 336.93 ab	5 902.90 ± 1 487.92 ab	0.27 ± 0.02 a

Table 2 Results of chieh-qua texture determination under different parameter conditions via puncture test

Detection parameter	Level	Skin hardness//g	Skin toughness//mm	Flesh hardness//g	Fracturability//g · s	Compactness//g · s
Trigger force//g	5	366.13 ± 50.82 b	1.20 ± 0.31 a	497.85 ± 59.69 a	2 282.40 ± 630.84 a	53.67 ± 2.58 a
	10	637.32 ± 214.57 ab	1.71 ± 0.33 a	528.52 ± 52.96 a	1 986.19 ± 236.33 a	72.53 ± 14.23 a
	15	944.629 ± 380.81 a	1.71 ± 0.13 a	721.51 ± 252.63 a	2 583.18 ± 770.02 a	81.40 ± 13.3 a
	20	534.56 ± 189.33 ab	1.42 ± 0.18 a	658.33 ± 143.36 a	2 076.99 ± 576.83 a	59.94 ± 11.05 a
	25	558.46 ± 168.22 ab	1.54 ± 0.45 a	592.30 ± 78.99 a	2 005.95 ± 425.19 a	75.31 ± 41.83 a
Puncture speed//mm/s	1	487.85 ± 324.53 a	1.78 ± 0.72 a	664.08 ± 71.57 a	2 381.23 ± 619.05 a	98.53 ± 39.68 a
	2	570.40 ± 130.08 a	1.41 ± 0.06 a	656.84 ± 39.84 a	2 494.59 ± 188.36 a	89.60 ± 21.59 a
	3	498.18 ± 182.57 a	1.23 ± 0.23 a	670.45 ± 103.84 a	2 493.35 ± 321.24 a	89.80 ± 28.60 a
	4	771.99 ± 151.22 a	1.21 ± 0.20 a	684.66 ± 125.69 a	2 731.16 ± 325.56 a	126.42 ± 25.28 a
	5	861.24 ± 263.21 a	1.21 ± 0.47 a	619.80 ± 40.52 a	2 407.95 ± 210.10 a	102.04 ± 33.15 a
Puncture depth//mm	3	663.18 ± 156.41 a	1.50 ± 0.27 ab	639.91 ± 138.22 a	427.18 ± 243.10 d	3.45 ± 0.41 c
	6	575.34 ± 131.55 a	1.76 ± 0.04 a	613.74 ± 106.56 a	1 264.87 ± 433.31 c	15.75 ± 3.57 c
	9	562.73 ± 284.18 a	1.42 ± 0.43 ab	599.43 ± 128.82 a	2 210.22 ± 246.42 b	49.97 ± 10.05 c
	12	682.51 ± 165.52 a	1.82 ± 0.55 a	610.81 ± 98.86 a	2 833.15 ± 449.92 b	121.11 ± 70.19 b
	15	608.23 ± 214.34 a	0.83 ± 0.43 b	662.63 ± 114.63 a	4 037.67 ± 327.31 a	204.04 ± 41.85 a

Correlation of texture indicators in chieh-qua

As shown in Table 3, TPA flesh hardness exhibited an extremely significant negative correlation with springiness, cohesiveness, and resilience ($P < 0.01$), with correlation coefficients of 0.880, 0.837, and 0.927, respectively. In contrast, springiness, cohesiveness and resilience showed extremely significant positive correlations with each other ($P<0.01$), with correlation coefficients ranging from 0.910 to 0.971, indicating that greater springiness was associated with higher cohesiveness and resilience in the flesh. Gumminess and chewiness also exhibited an extremely significant positive correlation ($P<0.01$), with a correlation coefficient of 0.982. It indicated that chieh-qua with higher gumminess inevitably had higher chewiness.

Table 3 Correlation among the textural characters of chieh-qua via TPA test

	TPA hardness	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
TPA hardness	1.000						
Adhesiveness	0.141	1.000					
Springiness	-0.880**	0.059	1.000				
Cohesiveness	-0.837**	0.062	0.971**	1.000			
Gumminess	0.340	0.411	0.074	0.194	1.000		
Chewiness	0.234	0.360	0.238	0.337	0.982**	1.000	
Resilience	-0.927**	-0.267	0.949**	0.910**	-0.101	0.057	1.000

** indicates a significant correlation at the 0.01 level (two-tailed).

The results in Table 4 showed that the skin hardness measured by puncture testing exhibited an extremely significant positive correlation with skin toughness ($P<0.01$), with a correlation coefficient of 0.755, indicating that higher skin hardness was associated with greater skin toughness during puncture. Fracturability and compactness also showed an extremely significant positive correlation ($P<0.01$), with a correlation coefficient of 0.933, meaning that higher fracturability corresponded to greater compactness. No significant correlations were observed among other texture indicators.

Table 4 Correlation among the textural characters of chieh-qua via puncture test

	Skin hardness	Skin toughness	Flesh hardness	Fracturability	Compactness
Skin hardness	1.000				
Skin toughness	0.755**	1.000			
Flesh hardness	0.477	-0.062	1.000		
Fracturability	0.099	-0.480	0.236	1.000	
Compactness	0.197	-0.490	0.309	0.933**	1.000

** indicates a significant correlation at the 0.01 level (two-tailed).

Discussion

The texture quality of fruits is a critical factor determining taste perception and plays a decisive role in consumer selection of chieh-qua. Therefore, research on texture parameters of chieh-qua is of significant importance for scientifically evaluating its texture quality. Different fruits require distinct texture detection methods. Currently, common methods for assessing texture quality in cucurbits crops include puncture testing and texture profile analysis (TPA). Using a needle-shaped probe for puncture testing can effectively reflect the texture of both the fruit surface and the flesh, but it also has certain limitations[22]. Due to the small contact area of the probe, selecting the puncture point is particularly crucial. The outer flesh of the chieh-qua, which is closely attached to the waxy layer of the rind, is harder, while the inner flesh, the primary edible part, has a looser texture. Additionally, as removing the rind and the spongy pith are necessary during consumption and processing, it is essential to select the inner flesh for measurement. TPA testing simulates the process of chewing food with teeth to obtain relevant texture parameters. This method requires selecting a certain volume of flesh for compression operations and is primarily applied to larger fruits such as apples[7], pears[15], watermelons[9], and melons[10]. TPA is susceptible to the influence of fruit size, shape, and tissue proportions[23], whereas the puncture method is not affected by these factors. Therefore, combining the puncture method and TPA can provide a comprehensive and accurate description and analysis of the texture quality of chieh-qua.

In this study, trigger force, puncture speed and other parameters were used as single-factor variables in puncture tests on the flesh of chieh-qua. It was found that trigger force had no significant effect on skin toughness or flesh texture, which is consistent with the conclusions drawn from texture parameter analyses of fruits such as Sanhua plum[4] and fig[24]. Using the TPA method to analyze the texture quality of chieh-qua, it was found that TPA hardness showed an extremely significant negative correlation with springiness, cohesiveness, and resilience. In contrast, Yang *et al.*[17], when conducting TPA tests on thick-skinned melons, observed an extremely significant positive correlation between TPA hardness and springiness, chewiness, and cohesiveness. It is hypothesized that differences in experimental materials and parameter conditions may have led to the observed discrepancies in results. Additionally, the study of Han *et al.*[25] confirmed that while texture quality showed no significant differences among grapes of the same variety but varying sizes, the influence of different parameters on TPA test results was more pronounced across different grape varieties. In this study, only one variety of chieh-qua was selected as the test material for texture analysis, and no comprehensive comparative analysis has yet conducted with the texture characteristics of other Chieh-qua types. Further and more detailed research will be carried out in the future.

Conclusions

In this study, a texture measurement and evaluation method for Chieh-qua was preliminarily established by combining TPA (texture profile analysis) with puncture mode. This method can accurately and quantitatively reflect differences in the texture quality of chieh-qua fruits. Following the analysis and comparision on the effects of different trigger forces, deformation levels, compression speeds, puncture speeds, and puncture depths on texture indicators, the optimal conditions for measuring chieh-qua texture using the TPA mode were determined as follows: trigger force of 15 g, 50% deformation, and compression speed at 3 mm/s. Among these, the trigger force had little impact on the texture indicators of chieh-qua. For the puncture mode, the conditions for measuring chieh-qua texture were set as: trigger force of 15 g, puncture depth of 12 mm, and puncture speed ranging from 2 to 4 mm/s. Notably, puncture speed did not have a significant effect on the texture indicators of chieh-qua. It has been clarified that hardness, springiness, chewiness and fracturability are important indicators for evaluating the texture quality of chieh-qua. This method can be applied to texture analysis of cucurbitaceous vegetables such as chieh-qua and wax gourd, providing a scientific basis for variety selection, quality assessment, and processing utilization of chieh-qua.

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