EFFECTS OF PINEAPPLE CONSUMPTIONS ON SENSORY PERCEPTIONS, SOMATOSENSATION AND TASTE THRESHOLD

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by

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"If people are doubting how far you can go, go so far that you can't hear them anymore"

Michele Ruiz

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LIST OF SYMBOLS

%	Percentage
°C	Degree Celsius
g	Gram
mg	Milligram
ml	Milliliter
µM	Micromolar
ppm	Parts per million
cm^3	Centimeter cube
$[Ca^{2+}]_{in}$	Concentration of intracellular cation
L	Lightness
a	Redness
b	Yellowness

LIST OF ABBREVIATIONS

MT	Metric tonnes
MPIB	Malaysia Pineapple Industry Board
DOA	Department of Agriculture
FAMA	Federal Agricultural Marketing Authority
QDA	Quantitative Descriptive Analysis
JAR	Just-about-right
CATA	Check-all-that-apply
gLMS	general Labelled Magnitude Scale
VAS	Visual Analog Scale
PCA	Principal Component Analysis
HCA	Hierarchical Cluster Analysis
CA	Correspondence Analysis
TSS	Total Soluble Solids
TA	Titratable Acidity
T1Rs	Sweet taste receptor
T2Rs	Bitter taste receptor
TRPs	Transient Receptor Protein
TRP	Transient Receptor Potential channel
TRPV	Transient Receptor Potential Vanilloid
TRPM	Transient Receptor Potential Melastin
TRPA1	Transient Receptor Potential subfamily Ankyrin
GPCR	G-protein coupled receptor, α-gustducin
AC	Adenyl Cyclase

PLC	Phospholipase C
PDE	Phosphoditerase
PKA	Protein Kinase A
cAMP	cyclic Adenosine Monophosphate
IP3	Inositol Trisphosphate
DAG	Diacyl Glycerol

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KESAN PENGAMBILAN NANAS TERHADAP PERSEPSI SENSORI, SOMATOSENSORI DAN AMBANG RASA

ABSTRAK

Kajian ini bertujuan mengenalpasti kesan pengambilan nanas terhadap persepsi sensori, somatosensasi, dan ambang rasa. Penerimaan dan pengambilan nanas dalam kalangan penguna diselidik, dan ciri-ciri fizikokimia dan penerimaan deria tiga jenis varieti nanas yang di tanam di bahagian utara semenanjung Malaysia (Moris, N36, dan MD2) pada pelbagai peringkat kematangan dikaji. Kaji selidik dijalankan secara atas talian terhadap 167 responden dengan menggunakan soal selidik yang ditadbir sendiri oleh responden. Sejumlah 28.1% responden enggan mengambil nanas kerana ia menyebabkan rasa tidak menyenangkan pada lidah (67.1%) dan menjejaskan deria rasa (19.1%) selepas pengambilannya. Walaupun pengambilan nanas segar menyebabkan kerengsaan pada lidah, tetapi pengguna tetap lebih gemar nanas segar (61%) berbanding nanas yang diproses kerana kandungan vitamin C, serat, dan enzim bromelinnya, serta rasanya yang menarik. Plot analisa komponen utama (PCA) dengan nilai varians 80.16% menunjukkan ciri-ciri fizikokimia seperti kecerahan (nilai L), tekstur, keasidan, dan kandungan vitamin C adalah faktor penting yang mempengaruhi penerimaan pengguna terhadap buah tersebut. Nanas yang dituai pada Index 4 dan Index 5 adalah sesuai untuk pengunaan buah segar kerana sifat teksturnya dan tahap penerimaan sensori buah tinggi. Nanas Moris dan N36 mempunyai persamaan (>80%) dari segi ciri-ciri fizikokimia dan penerimaan pengguna, manakala MD2 mempunyai kualiti organoleptik yang berbeza seperti lebih manis, kurang berasid, tinggi kandungan vitamin C, dan lebih aromatik berbanding nanas Moris dan N36. Kajian

selanjutnya dalam pemprofilan deria dijalankan terhadap nanas Moris kerana ianya mudah diperolehi, mempunyai keseimbangan gula-asid yang baik, dan kerangupan yang menarik minat pengguna mengambilnya pada semua peringkat kematangan. Kaedah *Check-all-that-apply* (CATA) telah dilaksanakan terhadap 75 orang pengguna dalam mencirikan kualiti sensori nanas pada lima peringkat kematangan. Berdasarkan analisi koresponden (CA), pengguna secara berkesannya mencirikan nanas Moris pada pelbagai peringkat kematangan bagi ciri-ciri fizikal dan kimia, dengan jumlah varians yang masing-masingnya 97.7% dan 92.2%. Perubahan fisiologi seperti sifat-sifat fizikokimia dan kandungan biokimia, mempengaruhi pemprofilan organoleptik dan penerimaan buah nanas. Moris yang dituai pada Index 4 hingga Index 6 untuk pengambilan segar adalah lebih disukai kerana penampilannya, teksturnya yang tidak keras, berserat, dan berair, tiada bau masam, bau manis yang sedikit, dan rasa masam-manis yang sekata. Seterusnya, kesan pengambilan nanas terhadap somatosensasi dan ambang rasa telah dikaji menggunakan 40 orang pengguna terpilih (dibahagikan kepada dua kumpulan). Tahap sensasi kebas, kegatalan, dan sakit pada lidah diukur dengan menggunakan skala 7 (0-tiada sensasi, 1-mula mengesan sensasi, 2-sensasi yang sangat ringan, 3-sensasi ringan, 4-sensasi ringan ke sederhana, 5-sensasi sederhana, 6-sensasi sederhana ke kuat, 7-sensasi sangat kuat) terhadap 20 orang subjek. Pengambilan sehingga 200 g nanas pada semua peringkat kematangan mengakibatkan sensasi kebas (1.42 ke 1.83), kegatalan (1.30 ke 1.83), dan sakit (0.88 ke 1.92) yang sangat ringan (skala 2) ke ringan (skala 3) pada lidah. Selain itu, pengambilan nanas serendah 50 g memberi kesan yang ketara ($P<0.05$) terhadap ambang rasa dalam kalangan 20 orang subjek. Keseluruhannya, ambang kemanisan pada subjek menigkat selepas pengambilan nanas pada semua peringkat kematangan, manakala ambang kepahitan pada subjek menurun selepas pengambilan nanas pada

Index 3 dan Index 4. Kesimpulannya, pengambilan nanas pada peringkat kematangan yang berbeza menghasilkan kualiti fizikokimia dan organoleptik yang optimum bagi setiap kematangan, yang mempengaruhi penerimaan dan pengunaan buah. Selain itu, pengambilan nanas harus dielakkan oleh penguna sebelum mengambil bahagian dalam penilaian deria makanan bagi mengelakkan penilaian yang tidak tepat.

EFFECTS OF PINEAPPLE CONSUMPTIONS ON SENSORY PERCEPTIONS, SOMATOSENSATION AND TASTE THRESHOLD

ABSTRACT

This study aims to determine the effects of pineapple consumptions on sensory perceptions, somatosensation, and taste threshold. The acceptance and consumption of pineapples among consumers were surveyed, and physicochemical and sensory acceptance of three pineapple varieties planted in the northern part of peninsular Malaysia (Moris, N36, and MD2) at various maturity stages were determined. The survey was conducted online with 167 respondents using a self-administrated questionnaire. A total of 28.1% of respondents refuse to eat pineapple because it causes an unpleasant feeling on the tongue (61.7%) and affects taste sensation (19.1%) after consumption. Although consuming fresh pineapple causes tongue irritation, consumers still prefer fresh fruit (61%) over processed pineapple due to its vitamin C, fibres, and bromelain enzyme, as well as its appealing flavour. Principal component analysis (PCA) plot with 80.16% variance shows that physicochemical properties such as lightness (*L* value), textures, titratable acidity, and vitamin C are important factors that influence consumer acceptance of the fruit. Pineapples harvested at Index 4 and Index 5 are suitable for fresh fruit consumption due to the texture and sensory acceptance of the fruit. Moris and N36 pineapples are nearly identical (>80% similarity) in terms of physicochemical properties and consumer acceptance, whereas MD2 has distinct organoleptic qualities such as being sweeter, less acidic, higher in vitamin C and more aromatic compared to Moris and N36. Further investigation on the sensory profiling of pineapples was conducted on the Moris variety due to easy to obtain, has a good sugars-acids balance, and crunchiness texture that attracts consumers to consume at all stages of maturity. Check-all-that-apply (CATA) analysis was conducted on 75 consumers to describe the sensory qualities of pineapple at five maturity stages. Based on correspondence analysis (CA), consumers effectively described Moris pineapple at various stages of maturity for their physical and chemical properties, with total variances of 97.7% and 92.2%, respectively. Physiological changes such as physicochemical properties and biochemical composition, influence organoleptic profiling and pineapple acceptance. Moris harvested at Index 4 to Index 6 for fresh consumption are preferred because of its attractiveness, soft, fibrous, and juicy texture, lack of sour odour, mild sweet odour, and sweet-sour taste. Following that, the effect of pineapple consumptions on somatosensation and taste threshold was studied over 40 selected consumers (split into two groups). The degree of unpleasant sensations of numbness, itchiness, and pain sensations on the tongue was measured using 7-point scales (0-none, 2-very mild, 3-mild, 4-mild to moderate, 5-moderate, 6-moderate to strong, 7-strong) against 20 subjects. Consumption of up to 200 g pineapple, at all stages of maturity results in a very mild (scale 2) to mild sensations (scale 3) of numbness (1.42 to 1.83), itchiness (1.30 to 1.83), and pain (0.88 to 1.92) on the tongue. Furthermore, consumption as low as 50 g pineapples had a significant (P<0.05) impact on taste threshold among 20 subjects. Overall, subjects' sweetness thresholds increased after consuming pineapples at all maturity stages, while subjects' bitterness thresholds decreased after consuming Index 3 and Index 4 pineapples. As a conclusion, harvesting pineapples at different stages of maturity results in optimal physicochemical and organoleptic qualities for each maturity, which affects the acceptance and use of the fruit. Besides, consumption of pineapple should be avoided

by consumers before participating in food sensory assessment to prevent an inaccurate assessment.

CHAPTER 1

INTRODUCTION

1.1 Research backgrounds

Tropical fruits are important to Malaysia as a source of income for Malaysians, a source of vitamins, minerals, and dietary fibres for humans, and as a way to generate revenue from trading activities. The trade of tropical fruit is increasing year by year due to increased demand from domestic and global markets (Dardak, 2019). In Malaysia, cultivation of tropical fruits such as durian, banana, rambutan, pineapple, and watermelon is carried-out in larger or commercial scale farms (≥10000 hectare), which follow the good manufacturing practices and are under the supervision of the Ministry of Agriculture and Agrobased Industry (Dardak, 2019). Among the fruits, the highest per capita fruit consumption by the Malaysian population is durian (11.1 kg), followed by banana (9 kg) and pineapple (7.2 kg) (MAFI, 2020). However, according to Tan et al. (2022), fruit consumption among Malaysian adults is considered low, with only 9.7% having an adequate fruit intake, which is at least two servings per day.

Pineapple (*Ananas cosmosus*) is a non-seasonal tropical fruit that widely planted worldwide and highly valued for its appealing flavour and refreshing sugar-acid balance. The important source of sugars, fibre, organic acids, minerals, vitamins and protease enzyme, bromelain in pineapple is crucial for human health (Hossain et al., 2015; Ali et al., 2020). Changes in fruit quality and palatability as well as fruit perception and acceptance are frequently associated with changes in pineapple composition (Montero-Calderón et al., 2010; Steingass et al., 2015). Besides that, the quality of pineapple is also dependent on changes in the fruit's physicochemical properties and nutritional qualities due to various factors including fruit genetics or variety, plantation demographics, plantation management, harvesting, storage, packaging, and transportation (Tyagi et al., 2017; Mopera, 2016; Mirza et al., 2016; Wahab and Khairuddin, 2020).

Among all nine pineapple varieties planted in Malaysia, Moris, MD2, and N36 varieties are widely cultivated for the domestic and export in fresh market due to their high tolerance to stress and disease, as well as have a longer lifespan after harvest (De Silva et al., 2008, Mohammad et al., 2012; Thalip et al., 2015). High aroma active compounds of Moris, MD2, and N36 varieties produce pineapple with fresh and fruity aroma, sweet, floral, and apple-like aroma, and woody and green flavours, respectively (Lasekan and Hussein, 2018). Different pineapple varieties, such as Moris, N36, and MD2 have been reported to have different physicochemical and nutritional qualities, which influence organoleptic characteristics related to consumer acceptance of the fruit (Wardy et al., 2009; Lu et al., 2014; Yuris and Siow, 2014). MD2 variety had higher preference score given by Malaysian on its aroma, sweetness, and colour as compared to other varieties, while Moris variety is the most preferred on their crunchiness texture and balance sweet-sour flavour (Syahrin, 2011; Yuris and Siow, 2014). Additionally, the loss of pineapple quality can also be attributed to fruit post-harvest handling by farmers (30-40%) (Hossain et al., 2015; Mopera, 2016; Wahab and Khairuddin, 2020). Harvesting at a proper maturity is crucial for ensuring the best pineapple quality which influence consumers' sensory acceptance (Viana et al., 2020). Previous studies reported that pineapple fruit harvested at different maturity stages varies in physical properties and chemical composition (Truc et al., 2008; Nadzirah et al., 2016; Steingass et al., 2014; Ding and Syazwani, 2016). Changes in physiological maturation of pineapple including texture, colour, taste, aroma, and flavour, influenced fruit palatability and consumer perception (Montero-Calderón et al., 2010; Steingass et al., 2015).

However, pineapple consumption has been associated with unpleasant feelings such as stinging, rawness, numbness, burning, or even bleeding on the lips, tongue, or cheeks in some people (Gould, 2021; Minger, 2021), which could influence consumer perception of taste (Braud and Boucher, 2020; Mistretta and Bradley, 2021). Pineapple contains a primary source of protease enzyme, bromelain and is enriched with organic acids including citric acids, ascorbic acid, and malic acid (Hossain et al., 2015; MPIB, 2020). Bromelain and organic acids are not only crucial for pineapple development, but they are also widely employed in the food industry as a meat tenderizer (Singh et al., 2018; Hui et al., 2020; Hafid et al., 2021). Bromelain is widely used as a meat tenderizer in a variety of meat proteins, including beef, chicken, and squid (Manohar et al., 2016; Singh et al., 2018, Hui et al., 2020; Hafid et al., 2021). Bromelain application to meat not only softens the protein muscle, but it also improves the organoleptic qualities of the meat (Hafid et al., 2021) and has excellent resilience of fish balls from golden pomfret (Feng et al., 2017).

Besides, plant protease, such as actinidin found in kiwifruit, have been extensively used in dental and oral care fields for cleaning the tongue surface (Yoshida et al., 2004; Yoshimatsu et al., 2006). In a similar way to the human mouth, plant protease is believed to be able to break down proteins on the surface of the tongue, lips, and cheeks that contain taste cells, essentially digesting them. Previous studies found that excessive consumption of fruits containing protease, organic acids, and phenolic compounds such as kiwi fruit, lemon, and lingonberry causes irritation, warmth, burning, and pungent sensations on the tongue (Walker and Prescott, 2003; Leksrisompong et al. 2012; Viljanen et al., 2014). Walker and Prescott (2003) discovered that eating kiwi fruit not only irritated the tongue, but also boosted sourness and suppressed sweetness perception. Another study demonstrates that applying 1 mg of the pronase enzyme from *Streptomyces griseus* to the tongue for 20 minutes reduced sweetness intensity (Hiji, 1975).

Although much research has been conducted on physicochemical and nutritional composition in determining pineapple qualities at different varieties (Wardy et al., 2009; Syahrin, 2011; Lu et al., 2014; Yuris and Siow, 2014; Lasekan and Hussein, 2018) and maturity stages (Truc et al., 2008; Pauziah et al., 2013; Steingass et al., 2014; Ding and Syazwani, 2016; George et al., 2016), no studies have been conducted on the relationship between physicochemical properties of pineapple at various varieties and maturity stages with consumer acceptance. Since Moris pineapple is mostly available in Malaysian markets, has a good sugar-acid balance, and crunchiness texture that capture consumers' attention and make them to eat it fresh at various stages of maturity, it is important to use the sensory approach in determining pineapple sensory profiling at various stages of maturity to ensure the best eating quality of the fruit. Consumption of pineapple had also caused unpleasant feelings on the tongue, that influence taste perceptions in humans (Gould, 2021; Minger, 2021) as similarly found in previous study after consuming kiwi fruit (Walker and Prescott, 2003). However, no scientific research has been done on the effect of pineapple consumption on human taste sensitivity. Therefore, in the present study, the used of sensory approaches in describing pineapple qualities and characteristics, as well as fruit acceptance, is crucial to be studied since there are increasing demand for pineapples recently. In addition, it is important to study the post-consumption effect of pineapple towards human perception and tongue sensitivity.

In the first chapter, a survey of consumers was conducted to gather information on their eating habits and perceptions of pineapples in relation to their physicochemical properties and consumer acceptability of the fruit. It is focused on the pineapple varieties planted in the northern part of peninsular Malaysia, which are Moris, MD2, and N36 at different maturity stages.

The physicochemical properties, sensory perception, and acceptance of pineapple at various maturity stages were then investigated in the second chapter in order to determine the best eating quality of the fruit. This chapter is focused on the Moris variety because it is readily available, has a good balance of sugar and acid, and a crunchy texture that attracts consumers to consume it at all stages of maturity as compared to other varieties. The used of sensory approach of Check-all-that-apply (CATA) is crucial in determining the sensory profiling of pineapple at various maturity.

Furthermore, the effect of Moris pineapple consumption on human taste sensation and sensitivity was further investigated. In the third chapter of the study, the degree of unpleasant sensation on the tongue after consuming pineapple at various maturity stages was measured against a selected subject. In the last chapter, a taste detection and recognition threshold study were applied to determine the sensitivity of human taste towards four basic tastes after consuming pineapple at various stages of maturity.

1.2 Objectives of the study

1) To explore the consumer perceptions of and eating behaviours toward pineapple through a survey and examining the relationship between the physicochemical properties and the consumer acceptability of pineapples at different varieties and stages of maturity.

2) To investigate the physicochemical properties, sensory characteristics, and consumer acceptability of Moris pineapples at different maturity stages by using Check-all-that-apply (CATA) analysis.

3) To determine the effects of pineapple intake on the degree of unpleasant sensation on the tongue.

4) To determine the effect of pineapple intake on human taste detection and recognition threshold based on fruit maturity.

CHAPTER 2

LITERATURE REVIEW

2.1 Pineapple

Pineapple (*Ananas comosus*) is a tropical fruit native to Brazil, Bolivia, and Paraguay that is widely farmed worldwide. According to the worldwide pineapple producer statistical database in 2019, Costa Rica is the world's leading pineapple grower, with a production of 3,328,100 metric tonnes (MT) of pineapple. The next largest producers were Philippines (2,747,856 MT), Brazil (2,426,526 MT), Indonesia (2,196,450 MT), and China (1,727,607 MT). Malaysia is the world's number 23 pineapple grower, with 299,912 MT produced (Firatoiu et al., 2021). In terms of both production and consumption, Asia is viewed as the pineapple's fastest growing market. Indians, Thais, Chinese, Indonesians, Malaysians, and the Philipinos consumed 34% of the world's pineapples in 2019 (Firatoiu et al., 2021).

Pineapple is planted all over Malaysia (Figure 2.1). Johor is the largest pineapple producer, accounting for 212,129.60 metric tonnes in 2020, followed by Sarawak, and Sabah. According to the Malaysia Pineapple Industry Board (MPIB), pineapple was grown to meet two market needs: fresh consumption and production purposes. A total of 14.8% of the pineapple production is for fresh fruit consumption, while 82.9% of the pineapples were processed into canned, juice, and agro-based products (e.g., cordial, jam, and food ingredients), and ornamental (2.3%) (MPIB, 2020). In 2020, pineapple production in Malaysia is mainly for fresh consumption, which is 70% remains domestic while 30% of fresh pineapples are exported to Singapore, Bahrain, China, Egypt, Japan, Jordan, Oman, Qatar, Saudi Arabia, Turnisia, Turkey, Ukraine, and United Arab Emirates (MPIB, 2020).

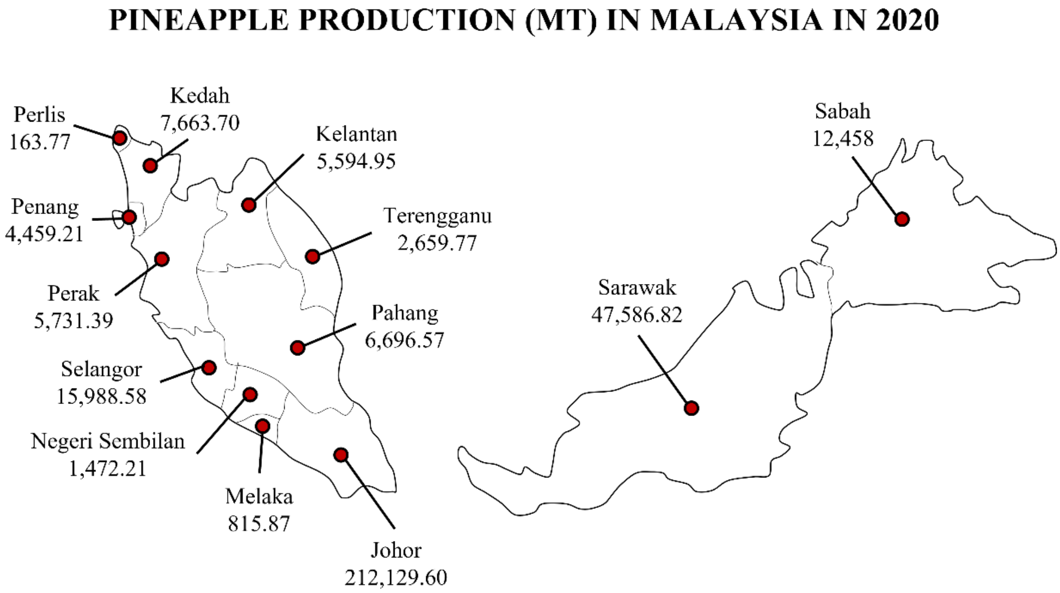


Figure 2.1 Pineapple production in Malaysia in 2020.
Source: DOA (2020).

Global fresh pineapple export values have increased by 58.2% over the last ten years, as consumers seek more fresh fruits compared to canned pineapple (Hommel, 2020). Fresh pineapples are in high demand due to their unique flavour and balance of sweet and acidic tastes that can be eaten just like that, made into a juice, or added to salads, and many types of dishes like “sweet and sour gravies”, “masak lemak”, “salted fish curry”, “laksa” and so on. Besides that, pineapple also has a lot of health benefits (Hossain et al., 2015; Ali et al., 2020).

2.1.1 Morphology

Pineapple is a herbaceous plant belongs to Bromeliaceae family. It thrives in both tropical and subtropical regions. Pineapple plant can reach height of 1 to 2 meters and have spirally arranged leaves. It comprised of crown, skin, eyes, flesh, and stem of a pineapple plant. A pineapple crop is cultivated at an optimum temperature of 24 to 30°C with annual rainfall distribution of 100-150 cm. Pineapple is suitable for planting in any soil type such as peat and mineral soil with a pH of 4.5 to 6.0 (MPIB, 2020). Pineapples can be harvested after 54 weeks of planting, depending on the desired fruit ripeness according to market demands. The stem was cut 6' long from the bottom of the fruit by using a sharp knife followed by grading the fruit. Pineapples are graded according to their variety, size, and maturity stages. Pineapples are categorised into three sizes: small (< 1 kg), medium (1.0 – 1.5 kg), and large (> 1.5 kg) (MPIB, 2020; FAMA, 2021).

2.1.2 Pineapple varieties and maturity stages

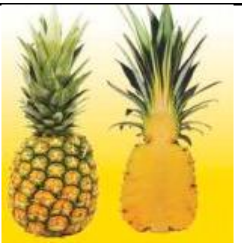
Pineapple is categorised into four groups, which are 'Queen', 'Red Spanish', 'Smooth Cayenne' and 'Hybrids'. There are nine pineapple varieties planted for the fresh and canning markets. Table 2.1 presents the classification of pineapple cultivars as published by the Malaysia Pineapple Industry Board (MPIB) in 2020. The shape of pineapple fruit varies depending on the cultivar, which is usually oval or cylinder in shape. Each pineapple cultivar has its own characteristics such as skin and flesh colour, total eyes, core size, sugar, and acid content, as well as its application, as summarized in Table 2.1.

Gandul was classified as "Red Spanish", with dark purple skin and golden yellow flesh. Gandul has less sugar and acidity in the flesh, with 8-12°Brix and 0.15-0.25%, respectively. It is a robust crop that is mainly produced for canned processing, such as flip top, pineapple cubes, pineapple juice, and pineapple slices (MPIB, 2020). Sarawak varieties is belonged to 'Smooth Cayenne', which is larger in size than other varieties and has a green-orange skin. Sarawak pineapple possesses 14 to 17°Brix total sugars and 0.3 to 1.2% acidity in the flesh as well as a longer life span, making it suitable for fresh consumption.

Table 2.1 Pineapple classification based on cultivar.

Cultivar					
	Gandul	**Sarawak**	**Moris**	**Moris Gajah**	**Yankee**
Group	Red Spanish	Smooth Cayenne	Queen	Queen	Queen
Weight	1.0 - 1.5 Kg	2 – 8 Kg	0.8 – 2.0 Kg	3.0 - 6.0 Kg	1.0 – 2.1 Kg
Shape	Cylinder	Oval	Oval	Cylinder	Oval
Skin colour	Dark purple	Green orange	Dark green	Dark purple	Light green
Total eyes	120 – 160	100 – 160	100 – 120	140 – 180	100 - 120
Wide core	1.8 – 2.2 cm	2.0 - 2.8 cm	2.0 cm	1.8 – 2.2 cm	1.0 – 1.5 cm
Flesh colour	Golden yellow	Golden yellow	Yellow, hollow, crunchy	Golden yellow	Clear white
Total sugars	8 - 12°Brix	14 – 17°Brix	12 – 14°Brix	12 – 14°Brix	11 -14°Brix
Citric acid	0.15 – 0.25%	0.3 – 1.2%	0.4 – 0.7%	0.3 – 0.5%	0.6 – 0.8%
Application	Canned processing	Fresh consumption	Fresh consumption	Fresh consumption	Fresh consumption

Table 2.1 (Continued).

Cultivar	 Maspine	 Josaphine	 N36	 MD2
Group	Hybrid	Hybrid	Hybrid	Hybrid
Weight	1.2 – 2.3 Kg	1.0 - 1.3 Kg	1.0 – 2.3 Kg	1.2 – 2.5 Kg
Shape	Cylinder	Cylinder	Cylinder	Cylinder
Skin colour	Light green	Red orange	Red orange	Bright green
Total eyes	120 – 140	120 – 140	120 – 140	120 - 160
Wide core	2.0 – 2.8 cm	2.0 – 2.8 cm	2.0 – 2.8 cm	2.1 – 2.2 cm
Flesh colour	Golden yellow	Golden yellow	Golden yellow	Golden yellow
Total sugars	12 – 14°Brix	16 – 17°Brix	16 -17°Brix	12 – 19°Brix
Citric acid	0.4 – 0.6%	0.5 – 1.2%	0.5 – 1.2%	0.05 – 0.3%
Application	Fresh consumption and canned processing	Fresh consumption	Fresh consumption	Fresh consumption

Source: Malaysia Pineapple Industry Board (MPIB), 2020.

The 'Queen' cultivar has a tapered fruit with skin colour ranging from dark purple to dark green and flesh colour ranging from clear white (Yankee), yellow with a crunchy texture (Moris), and golden yellow flesh (Moris Gajah). It is planted for fresh consumption, with total sugars and acid levels in the range of 11-14°Brix and 0.3-0.8%, respectively. Queen cultivars are resistant to stress, pests, and disease (De Silva et al., 2008). Moris has a stronger fruity and fresh aroma of pineapple than the other two types (Yankee and Moris Gajah) (Lasekan and Hussein, 2018). 'Hybrids' cultivars are created through breeding between cultivars to improve the fruits' characteristics and quality. The 'Hybrids' cultivars including Maspine, Josaphine, N36, and MD2 have golden yellow flesh. Josaphine, N36, and MD2 are cultivated for fresh consumption, whilst Maspine is grown for both fresh consumption and canning. Josaphine is the only pineapple variety that has short planting periods as compared to other variety which is 12 months (Abdul Ghani et al., 2018). Despite the fact that Josaphine and N36 have similar sugar (16-17°Brix) and acid (0.5-1.2%) content, N36 is categorized as a robust cultivar due to its longer lifespan and greater susceptibility to blackheart disease (Hassan et al., 2011; Mohammad et al., 2012). The N36 variety has a strong sweet and woody aroma due to its higher fatty acid methyl ester (Lasekan and Hussein, 2018). MD2 gained popularity due to the sweetest pineapple compared to other varieties, with total sugars ranging from 12 to 19°Brix, is less acidic (0.05-0.3%), and is more aromatic (Achuonjei et al., 2003; Wardy et al., 2009; Ding and Syazwani, 2016). MD2 has a high intensity of sweet, floral, and apple-like odour due to its high fruity esters (Lasekan and Hussein, 2018). It has a longer shelf life (Thalip et al., 2015), which increases demand for both the domestic and exported fresh markets. The production of MD2 was included under the 12th Malaysia Plan, 12MP (2021 to 2025), which the Malaysia Pineapple Industry Board aims to increase the production of the MD2 variety to 50% by increasing the plantation area from 16,000 hectares to 20,000 hectares (Bernama, 2021).

According to Abu Bakar et al. (2013) and Srivichien and Teerachaichayut (2014), pineapple ripeness is determined by variation in the colour of the pineapple skins. The change of the fruit's skin colour from dark green to orange begins at the bottom of the fruit and is distinguished by each maturity index (Table 2.2). Pineapples reach maturity after 120-170 days after the fruit begins to flower, depending on the variety (Federal Agricultural Marketing Authority, FAMA, 2021). Pineapple maturity indices were divided into seven categories: Index 1-immature or unmatured, Index 2-pre-mature, Index 3-mature, Index 4-under ripe, Index 5-early ripe, Index 6-ripe, and Index 7-fully ripe (FAMA, 2021). Farmers harvest pineapple at a level of maturity corresponding to market demand, as determined by FAMA based on visual observation (as in Table 2.2). Previously, the application of image processing techniques in determining pineapple ripeness based on variations in skin colour was investigated (Mohammad et al., 2012; Abu Bakar et al., 2013; Aguilar et al., 2021). It demonstrates that when compared to manual observations by farmers, this technique has an accuracy of more than 85% in determining fruit maturity. This approach, however, is not suitable for use on farms, and it is preferable for them to utilise the harvesting methods recommended by the Federal Agricultural Marketing Authority (FAMA).

Table 2.2 Classification of maturity stages of pineapple.

Maturity stages	Description
Index 1 	Young and unmatured Dark green of skin with the redness braktea Flesh is whitish
Index 2 	Pre-mature Dark green of skin and a little bit yellow colour between eyes at bottom area Flesh is whitish
Index 3 	Mature Green in colour of skin with 1 to 2 eyes at fruit base is yellow Flesh is whitish yellow and solid Suitable for export
Index 4 	Under ripe 25% of the fruit bottom colour of skin is change to yellowish Flesh is slight yellowish and solid Suitable for domestic market and eating fresh
Index 5 	Early ripe 50% of the fruit bottom colour of skin is change to yellowish Flesh is yellowish and less solid Suitable for domestic market and eating fresh
Index 6 	Ripe 75% of the fruit bottom colour of skin is change to yellowish Flesh is yellowish, little flaccid, and juicy Suitable for domestic market and eating fresh
Index 7 	Fully ripe 100% skin colour change to yellowish orange Flesh is intense yellow, flaccid, and too juicy Suitable for juice processing

Source: Federal Agricultural Marketing Authority, FAMA (2021).

2.1.3 Chemical compositions and nutritional values of pineapples

Pineapple is an important source of sugars, organic acids, essential minerals, fibre, vitamins, and enzyme, all of which are crucial for human nutrition (Hossain et al., 2015; Ali et al., 2020). In addition, pineapple is rich in health promoting antioxidants such as ascorbic acid, flavonoid, carotenoid, and phenolic acids (Hossain and Rahman, 2011; Lu et al., 2014). Pineapple flesh contains 47-52 calories, 87.8% moisture, 10.6-13.7% carbohydrate, 8-19% total sugars, 0.6-1.4% crude fibre and 0.5% protein per 100 g of fruit (Hossain et al., 2015; MPIB, 2020). Aside from that, pineapple fruit is also rich in vitamin C (15.2 to 21.5 mg/100g), organic acids (87% citric acid and 13% malic acid) (Saradhuldhat and Paull, 2007; Lu et al., 2014; Ding and Syazwani, 2016), minerals (potassium: 97 mg/100g, sodium: 31 mg/100g, calcium: 24 mg/100g, phosphorus: 6 mg/100g, and iron: 1.4 mg/100g) (Lu et al., 2014; MPIB, 2020), flavonoids (rutin: 6.16 - 27.31 mg/100 g, and quercetin: 39.4 – 55.2 mg/g), β-carotene (270 mg/100 g), phenolic acids (gallic acid: 31.48 - 77.55 mg/100 g and caffeic acid: 2.6 – 51.1 mg/g) (Hossain and Rahman, 2011; Lu et al., 2014; MPIB, 2020) and proteolytic bromelain enzyme (252-574 units/ml) (Nor et al., 2015; Misran et al., 2019). Pineapples contain a number of volatile and non-volatile compounds that blend together, contributing to the various aromas and flavours of the fruit, including sweet, floral, fruity, fresh, green, woody, and apple-like aroma and flavour (Umano et al., 1992; Lasekan and Hussain, 2018). Besides having a favourable flavour, pineapple contains balanced nutrients, antioxidants, and other useful compounds such as the enzyme bromelain, which can protect humans from inflammation, intestinal disorders, cancer, and disease (Hossain and Rahman, 2011; Lakshminarasimaiah et al., 2014; Nor et al., 2015).

2.1.4 Factors affecting pineapple quality

The quality of pineapple is determined based on its appearance, size, skin colour, texture, aroma of the fruit, and free from injuries and disorders (Hotegni et al., 2014; George et al., 2016; Wahab and Khairuddin, 2020). Fruits undergo physiological and biochemical changes that could affect their quality and thus the fruit palatability (Pauziah et al., 2013; Yuris and Siow, 2014; Lasekan and Hussein, 2018). Pineapples were planted in peat and mineral soils, and its quality varied due to a various factors including pre- and post-harvest factors (Tyagi et al., 2017; Mirza et al., 2016; Wahab and Khairuddin, 2020). According to Hossain et al. (2015) and Tyagi et al. (2017), pre-harvest factors such as climate, fruit genetics, plantation demography, cultivation techniques, and plantation management have a significant impact on the fruit's physiology and biochemical properties, as well as pineapple quality.

Besides, other factors that can cause the quality of pineapple loss are due to post-harvest handling including harvesting time, failure of sorting and grading, storage, and the transportation facilities (Mirza et al., 2016; Wahab and Khairuddin, 2020). Previous studies state that the greatest loss of pineapple quality, approximately 30 to 40%, is due to the lack of post-harvest handing, which is related to farmer skills such as lack of awareness, knowledge, and skills (Hossain et al., 2015; Wahab and Khairuddin, 2020) accompanied by distribution, transportation, and storage (Hossain et al., 2015; Mopera, 2016). Post-harvest handling of the pineapples by unskilled farmers or pineapple growers such as harvesting the fruit at an immature stage, rough handling, failure of sorting and grading, inadequate packing, improper pre-cooling, insufficient temperature during storage, and transportation leads to declining the quality of the fruit (Mirza et al., 2016). Correct post-harvest handling is one of the crucial factors that needs to be emphasised in order to reduce the loss of pineapple quality, which affects consumer perceptions and preferences for the fruit (Wahab and Khairuddin, 2020). Furthermore, harvesting pineapple at the right level of maturity is crucial for ensuring the best pineapple quality and high sensory acceptance by consumers (Viana et al., 2020). According to previous study, Fusarious-resistant pineapple (FRF 632) harvested at the coloured (up to 50% ripe) and yellow (more than 50% ripe) stages had the highest acceptance percentages with the ideal sweetness and acidity fruit (Viana et al., 2020).

2.1.5 Physiological changes towards chemical compositions and maturity stages

Pineapple is a non-climacteric fruit, meaning it grows and develops on the plant before being harvested. Since there are no carbon sources that can help pineapples become sweeter after they're harvested, they must be harvested at the right maturity to ensure the highest eating quality. Pineapple contains three major sugars, which are sucrose, glucose, and fructose, that play an important role as a source of carbon and energy in pineapple fruit growth and development (Park et al., 2009; Basson et al., 2010). In the early stages of pineapple development, fructose and glucose were the major sugars, accounting for 80% of total sugar. Sucrose in the fruitlets began to accumulate 20 days after flowering and continued until the end of fruit growth (Zhang et al., 2010a; Zhang et al., 2010b; Zhang et al., 2012). Sucrose is the primary source of sweetness of pineapple fruit and changes in sucrose metabolic activity during fruit growth caused sugar to build up in fruit tissue, which was an important physiological indicator (Chen and Paull, 2000; Koch, 2004; Zhang et al., 2010a). The accumulation of sugar during fruit development is caused by starch hydrolysis, depolymerization of matrix glycans and pectin, as well as the breakdown of the cell wall, which subsequently reduces cell firmness (Mercado et al., 2011; Posé et al., 2019).

Furthermore, organic acids are compounds that are also important in the growth and development of pineapple crops. During fruit development, organic acid levels are inversely compared to sugar levels. The accumulation of organic acids during the early stages is related to the supply of substrates in glycolysis and the tricarboxylic acid (TCA) cycle for the respiration process during fruit development (Truc et al., 2008; Etienne et al., 2013; Seymour et al., 2013). Ripening of pineapple is accompanied by organic acid degradation due to the activation of metabolic activity enzymes such as citrate dehydrogenase and citrate synthase, which results in the conversion of organic acids to soluble solids (Fernando and Silva, 2000; Truc et al., 2008). It resembles other fruit, such as apple (Ackermann et al., 1992), peaches (Etienne et al., 2013), strawberry (Basson et al., 2010), and pears (Sha et al., 2011) upon fruit ripening. Citric acid is a prominent organic acid found in pineapple that contributes to the tartness of the fruit. The balance of total sugars and acid in pineapple imparts the good flavour and aroma of the fruit, which determines its desirable eating quality (Noorlidawati et al., 2016; Lasekan and Hussein, 2018).

Bromelain enzyme, a cysteine proteinase found in all parts of the pineapple including crown, peel, flesh, and stem. The bromelain enzyme activity is higher in the crown (426.49 to 1106.11 casein digestion units (CDU/ml), followed by flesh (251.87 to 573.6 CDU/ml), peel (246.83 to 429.70 CDU/ml) and core (76.6 to 218.75 CDU/ml) (Lakshminarasimaiah et al., 2014; Nor et al., 2015; Misran et al., 2019). Bromelain enzyme is necessary for plant growth, development, and senescence (Grudkowska and Zagdańska, 2004; Wang et al., 2014). According to Chaurasiya and Hebbar (2013) and Wang et al. (2014), bromelain enzyme activity rises in the early stages of pineapple growth, but it decreases as the fruit ripens. Bromelain is highly expressed in the immature fruit which acts as an inhibitor of invertase activation (Neuteboom et al., 2009). Activation of invertase, a vacuolar hydrolytic enzyme causes the destruction of the fruit cell wall during the ripening process, resulting in a decrease in bromelain enzyme activity (Yamada et al., 2005; Wang et al., 2014). The physiological maturity of the fruit is influenced by the physical properties and chemical composition of pineapples on different varieties (Lu et al., 2014; Yuris and Siow, 2014; Lasekan and Hussein, 2018) and stage of maturity (Pauziah et al., 2013; Ding and Syazwani, 2016; George et al., 2016).

2.1.6 Health benefits

Pineapple has a positive impact on health and provides medical benefits to humans. Consumption of pineapples helps to prevent constipation and cure irregular bowel movement due to the high dietary fibres (0.6 – 1.4%) in the fruit (Hossain et al., 2015; MPIB, 2020). Furthermore, it aids in the maintenance of gastrointestinal health and may increase satiation, lowering the risk of obesity (Chiet, 2013). Pineapples are high in vitamin C and provide 131% of the recommended daily intake. It is essential for growth and development, as well as for immune system enhancement and iron absorption from the diet (Harris et al., 2013; Hossain et al., 2015). Pineapple also contains other vitamins such as Thiamine (B_1), Riboflavin (B_2), and Niacin (B_3), which provides 9%, 3%, and 4% of the recommended daily intake, respectively. It aids in the prevention of cancers and lowers the risk of coronary heart disease (Chiet, 2013). Pineapple's high mineral content, particularly potassium, is crucial for maintaining the salt balance in human tissue (Chiet, 2013; Lu et al., 2014). Pineapple is a good source of antioxidants, like vitamin C, flavonoids, carotenoids, and polyphenolic compounds. These antioxidants, which scavenge free radicals, may help prevent cancer (Bajpai et al., 2009; Hossain and Rahman, 2011). In addition, the bromelain enzyme found in pineapple also offers numerous health benefits. Bromelain is a group of digestive enzymes that break down protein, assisting in the treatment of inflammation, intestinal disorders, and improving antibiotic absorption (Nor et al., 2015). Bromelain can also help reduce platelet clumping and blood clots in the arteries, as well as improve white blood cell function (Lakshminarasimaiah et al., 2014).

2.1.7 How pineapple composition influences sensory perception

Pineapple quality is primarily determined by appearance, firmness, sweetness, sourness, and flavours (Keutgen and Pawelzik, 2008; Hotegni et al., 2014; George et al., 2016). Different varieties have varying sugars and acidity (Table 2.1), influencing the consumers' perception and acceptance of the fruit. Furthermore, the combination of sugar and acidity in pineapples develops various aromatic compounds that differentiate between the varieties and contribute to the pineapple flavours (Lasekan and Hussein, 2018). Moris and MD2 have the highest fruit esters when compared to other pineapple varieties in Malaysia, with Moris having a fruity and fresh aroma, while MD2 has a sweet, floral, and apple-like aroma. N36 has a strong sweet and woody aroma, whilst Josaphine has a comparable but less floral aroma to N36. Maspine has a strong sweet and green aroma, while Sarawak produces a strong woody and green aroma (Lasekan and Hussein, 2018). Previous studies show that high sugar and low acidity in MD2 pineapple provide a high consumer preference for sweetness and flavour when compared to Smooth Cayenne and Sugarloaf varieties (Wardy et al., 2009), Moris, Josaphine, and Maspine (Syahrin, 2011). A total of 45% of consumers in United States prefer Del Monte Hawaiì Gold because it is less tart and has a better pineapple flavour than Smooth Cayenne. This is due to the low acidity (0.45%) and high ratio of fruit sugars to acidity (TSS/TA of 27.2), and high vitamin C content (91 mg/100g) in the Del Monte Hawaiì Gold variety (Ramsaroop and Saulo, 2007). In addition, 59% of 269 consumers prefer the external sensory attributes of the Del Monte Hawaiì Gold variety as having huge 'eyes' on the green, orange skin colour with a sweet odour (Ramsaroop and Saulo, 2007).

Biochemical changes in pineapple fruits during ripening are primary contributors to physiological changes that lead to the production of edible fruit with the desired quality. The accumulation of sugar and soluble solids during fruit ripening reduces pineapple firmness by 36%. Meanwhile, the flesh colour intensity increases as maturity increases (Pauziah et al., 2013; Ding and Syazwani, 2016; George et al., 2016). Changes in sugar and acid levels in pineapple result in the development of flavour and aroma compounds in the fruit (Cordenunsi et al., 2010; Wei et al., 2011; Zheng et al., 2012; Steingass et al., 2016). Pineapple's sweet, sour, and aromatic flavours, which vary by variety and maturity, cause the fruit to be consumed fresh all over the world (Shahbandeh, 2022). Changes in pineapple composition have an impact on the sensory perception of fresh pineapple and are important in assessing fruit palatability. MD2 pineapple harvested at fully ripe (~147-157 days after flower induction) is the most preferred by consumers in term of odour (74%), taste (79%), and overall acceptance (79%) as compared to green-ripe fruit which were harvested ~137-145 days after flower induction (Steingass et al., 2015). Fully ripe MD2 develops a pineapple flavour, fruity flavour, and a sweet taste due to elevated concentration of 1,3,5,8-undecatetraene isomers, methyl 3-methylbutanoate and 4-methoxy-2,5-dimethyl-3(2*H*)-furanone (Steingass et al., 2015). However, no research has been done on the biochemical changes in pineapple in relation to physiological maturity in organoleptic perceptions. Several studies have been conducted to assess fruit quality based on sensory perception for various fruits, including sweet cherries (*Prunus avium*

L.) (Esti et al., 2002), berries (Viljanen et al., 2014; Stavang et al., 2015), mango (*Irvingia gabonensis*) (Kengni et al., 2017; Liguori et al., 2020), apple (*Malus domestica* Borkh.) (Chauvin et al., 2010; Corollaro et al., 2013), peach (*Prunus persica* L.) (Lopez et al., 2011; Wang et al., 2020), pear (*Pyrus* L.) (Chauvin et al. 2010), strawberry (*Fragaria x ananassa*) (Gunness et al., 2009; Schwieterman et al., 2014), melon (*Cucumis melo* L.) (Farcuh et al., 2020) and mandarin (*Citrus reticulata* Blanco) (Hijaz et al., 2020).

2.2 Consumer's sensory perception of fruit and fruit products

Human perceptions of food are too subjective, relying on the senses of sight, hearing, smelling, touch, and taste to determine the quality of fruits, vegetables, and food products. Sensory perception is defined as the relationship between physical input and a subject's response. It involves detecting input by the sense organs (i.e., eyes, ears, nose, hands, and tongue), processing it into nerve signals that travel to the brain for interpretation, recognition, and combining the information into perceptions (Meilgaard et al., 2006). The prominent tastes of foods, such as sweet and cooling ice cream, sour lime, bitter coffee, and the burning feeling of hot pepper, had an impact on consumer perceptions. Several studies have been conducted on human perceptions of the quality attributes of various types of foods, including fresh fruits (Chauvin et al. 2010; Corollaro et al., 2013; Viljanen et al., 2014; Steingass et al., 2015) and fruit products (Cadot et al., 2010; Bonneau et al., 2018; Olieveira et al., 2018; Pereire et al., 2019).

Table 2.3 summarizes the sensory perception of different type of fresh fruits including melon, mango, mandarin, pineapple, apple, pear, loquat, raspberry, and strawberry. The quality attributes of fresh fruit are determined based on the sensory perception of appearance (skin and flesh colour, skin tone, attractiveness, freshness), textures (firmness, fracturability, crunchiness, crispiness, juiciness, fibrousness), tastes (sweet, sour, and bitter), odour (fruity, floral, fresh, citrus, medicinal, grassy, herbaceous), flavours (fruity, floral, ripe, fermented, alcoholic, and astringent) and mouthfeel (graininess, mealiness, pungent, fresh).

2.2.1 Method used in determining fruit and fruit product attributes

Determination of fruit quality does not depend solely on instrumental or sensory methods. A combination of both instrumental and sensory methods could be used in determining the quality attributes of various fruits (Chauvin et al., 2010; Corrêa et al., 2014; Sarkar et al., 2020; Hijaz et al., 2020), vegetables (Zhuang et al., 2020; Wieczorek et al., 2022), and fruit/vegetable products (Kim et al., 2013; Ferreira et al., 2016; Yilmaz-Ersan and Topcuoglu, 2022). Hedonic judgement is commonly applied in determining the consumer acceptability of fruit goods (Ramsaroop and Saulo, 2007; Syahrin, 2011; Schwieterman et al., 2014; Pereira et al., 2020). On the other hand, the sensory characteristics of food products, can only be obtained through the consumer's descriptive method.

Table 2.3 Sensory perceptions of different types of fresh fruits.

Fresh fruits	Sensory method/ Number of panels	Sensory perceptions	References
Osteen mango fruit	Generated a list of descriptors (10 semi-trained panels)	Yellow skin and flesh colour Peach, exotic fruit, medicinal, burned oil, and cheese odour Peach, sea, exotic fruit, and medicinal flavour Sweet, sour/acidic, and bitter taste Juiciness, mealiness	Liguori et al., 2020
Mandarin	QDA (10 trained panels)	Ripeness, juiciness Sweetness, sourness, bitterness, pumpkin/spicy Tangerine, fruity-noncitrus, and floral flavour	Hijaz et al., 2020
Melon	QDA (9 trained panels)	Melon, fruity, grassy, green, sweet, melon rind, floral, and fermented/overripe aroma Sweet, sour/acid, and bitter taste Fruity, sweet, fermented/overripe, buttery, gassy, green, and after flavour	Farcuh et al., 2020
Loquat	QDA (10 trained panels)	Loquat, herbaceous, and floral odour Juiciness, sweet, acidic, bitter, astringent Loquat, herbaceous, and floral flavour	Farina et al., 2016
Raspberry	9-point scales (9 trained panels)	Freshness, attractiveness Sweetness, acidity, and bitterness	Stavang et al., 2015
Pineapple	QDA (10 trained panels)	Sweet, sour, bitter taste Fruity, pineapple-like, melon-like, honey-like, and citrus-like aroma	Steingass et al., 2015
Lingonberry	QDA (11 trained panels)	Fresh, redness colour, thickness, clarity Sour and fermented odour and flavour, sweetness, bitterness	Viljanen et al., 2014
Apple	QDA (13 trained panels)	Yellow flesh colour, sweet and sour taste Hardness, crunchiness, crispiness, graininess, fibrousness, flouriness, and juiciness	Corollaro et al., 2013

QDA is quantitative descriptive analysis, CATA is check-all-that-apply analysis.