Chemical characterization of odour-active volatile compounds during lucuma (Pouteria lucuma) fruit ripening

Marianela Inga, Juliana María García, Ana Aguilar-Galvez, David Campos and Coralia Osorio

ABSTRACT
Lucuma (Pouteria lucuma) is an important exportation fruit in Peru. In this work, the odour-active volatile changes during fruit ripening were studied by using a sensomics approach (GC-O in combination with GC-MS analyses). The volatile compound extracts from unripe and ripe fruits were obtained by solvent-assisted flavour extraction (SAFE) with dichloromethane. By application of the aroma extract dilution analysis (AEDA) on the ripe fruit extract, 16 odour-active compounds were detected as responsible of sweet, green, and rancid odour-notes, characteristics of this fruit. Based on odour activity value (OAV) calculation, 2,3-butanedione, methional, (Z)-3-hexenal, (E)-2-hexenal, (Z)-β-ocimene, and 3-methyl butanoic acid were identified as key-aroma compounds in this fruit. These compounds were also quantitated in the unripe fruit SAFE extract finding that their amount increased with during the ripening, such contributing to the development of characteristic odour notes.

1. Introduction
Lucuma (Pouteria lucuma) is a tropical fruit belonging to Sapotaceae family (Figure 1) and is widespread in the western South America. Peru is one of the main producers and exporters worldwide (SIICEX, 2019), because its different microclimates allow to have fruit throughout all year. This fruit is usually cultivated from 1500 to 3000 m above sea level, with a temperature range of 8–27°C and a relative humidity value of 80–90%. It was used by Inca culture, as one of the main ingredients of their diet, since much evidence was found in images moulded in “huacos” (ceramic pieces) of the Mochica culture (Ministerio de Agricultura del Perú, 2019a). The production of lucuma has remained almost constant during the last 3 years, reaching 14,040 tons in 2017 (Ministerio de Agricultura del Perú, 2019b).

The fruit pulp exhibits an intense yellow colour and characteristic aroma that allow us to use it for the preparation of different foods. Among them, ice creams and bakery products are the most consumed. Pouteria lucuma fruit has a low-moisture content (56.0–72.3% during consumption maturity stage) compared to other fruits; in contrast, protein content is high, varying from 1.5 to 3.3% (Erazo, Escobar, Olaeta, & Undurraga, 1999). This fruit is also rich in carotenoids; minerals, such as, calcium, phosphorus, and iron (Ministerio de Salud del Perú, 2009); as well as vitamins such as, thiamine, riboflavin, niacin and large amount of vitamin C (0.14–1.07 mg/100 g dry matter) (Fuentealba et al., 2016; Yahia & Gutierrez-Orozco, 2011). Lucuma pulp is the main presentation to export this fruit, which stimulates the development of processing technologies to preserve its properties.

Triterpenes, phenolic compounds and carotenoids are the main secondary metabolites in fruit extracts of Pouteria species, a tropical and subtropical genus (da Silva, Gordon, Jungfer, Marx, & Maia, 2012). Besides, in vitro antioxidant and antihyperglycemic (specifically a-amylase and α-glucosidase inhibitory activities) properties have been studied and were found dependent on ripening stage (da Silva Pinto et al., 2009; Fuentealba et al., 2016). Despite attractive sensorial

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characteristics of P. lucuma fruit, there is no any study in literature related to the chemical composition of aroma-active volatile compounds. Only the VOC profile of lucuma fruits exported to Italy was recently analysed by using PTR-MS-TOF measurements, tentatively identified more than 50 compounds (Taiti, Colzi, Azzarello, & Mancuso, 2017).

Usually, this fruit is harvested in unripe stage and after ca. 2 weeks the ripe stage is reached, which is characterized by a strong and pleasant aroma. Thus, the aim of this work was to identify the odour-active volatile compounds in this fruit, evaluate their contribution to the whole aroma and their change from unripe to ripe stages. The so-called molecular sensory approach (Schieberle & Hofmann, 2011) was used, what combines instrumental (GC-MS) and sensory (GC-O) analyses to focus the identification efforts only in those compounds that are aroma-active.

### 2. Materials and methods

#### 2.1. Fruits

Pouteria lucuma (biotype Dos Marron) fruits were harvested from a farm located in Fundo Huayquina, Chincha, Peru, July 2017. Fruits were randomized collected from 10 trees (yellow peel colour under the calix, unripe stage), and stored until they reached fully ripe stage (soft texture and brown-greenish peel colour). Physicochemical parameters, such as pH, total soluble solid content (°Brix), and acidity, were measured in both stages. For this purpose, each sample lot consisting of 4 units (ca. 1 Kg) of fruits was homogenized using a commercial stainless-steel blender. The pH of the fruits was determined by using a C6820 pH-meter (Schott Gerate, Berlin, Germany). The total soluble solid content (°Brix) and acidity were measured by titration of 10 g of puree diluted with 50 mL of water, titrated with 0.1 N NaOH and calculated as percent of citric acid (AOAC, 2006). All measurements were done in triplicate.

#### 2.2. Chemicals

An n-alkane mix (C₆-C₂₅) was purchased from Restek (Bellefonte, PA, USA). Pure reference standards of volatile compounds were acquired as follows: 2,3-butanedione, (E)-2-hexenal, (Z)-β-ocimene, 4-hydroxy-4-methyl-2-pentanone, methional, 2-methyl propanoic acid, butanoic acid, 3-methylbutanoic acid, and δ-octalactone were generously supplied by DISAROMAS S.A. (Bogotá, Colombia); (Z)-3-hexenal, ethyl 3-hydroxy-butanoate, and (3E)-hexenoic acid (Sigma-Aldrich, St. Louis, MO, USA). Dichloromethane, sodium sulphate (anhydrous), sodium chloride, acetic acid, and hexanoic acid were acquired from Merck (Darmstadt, Germany).

#### 2.3. Isolation of volatile extract by SAFE distillation

Ripe and unripe lucuma fruit pulps (300 g) were separately homogenized with anhydrous sodium sulphate (Na₂SO₄) and these mixtures were packed in a glass column, to elute volatile compounds with 300 mL of dichloromethane in each case. The organic phases so obtained, containing the aroma compounds, were subjected to SAFE (Solvent-Assisted Flavour Extraction) (Engel, Bahr, & Schieberle, 1999) and a colourless extract without non-volatile compounds exhibiting the characteristic fruit aroma was obtained. The organic extract was concentrated at 45°C on a Viguex column (50 cm x 1 cm) to a 0.2 mL volume to be analysed by GC-O and GC-MS.

#### 2.4. GC-O and GC-MS analyses

The GC-O analyses were performed in a Hewlett Packard 5890 series II gas chromatograph (Hewlett-Packard, Wilmington, DE, USA), equipped with a TR-FFAP column (Thermo, 30 m x 0.32 mm i.d., 0.25 μm film thickness). The injection (1 μL) was done in split mode (1:10). Helium was used as a carrier gas at flow rate of 1.2 mL/min. The oven temperature programme started at 40°C for 1 min, then the temperature was increased at 6°C/min until 180°C, then at 12°C/min until 230°C and finally held for 10 min. The final end of the column was connected to a deactivated Y-shaped glass splitter (Chromatographie Handel Mueller, Fridolfingen, Germany), to divide the effluent into two equal parts (1:1 ratio), one for to the conventional FID detector (230°C) and the other for the sniffing port (230°C) by using deactivated fused silica capillaries of the same length (50 cm x 0.32 mm). Sniffing port consisted of an elbow-shaped aluminium tube (80 mm x 5 mm i.d) self-made. Three trained panelists detected (every 20 min) the olfactory-active regions and described the odour notes perceived from each odour-active compound. The panelists were trained in the recognition of main descriptors of this fruit (green, sweet, and rancid-fermented), by the orthonasally evaluation of the corresponding reference odorants ((Z)-3-hexenal (green), butanoic acid (rancid), and 4-hydroxy-2,5-dimethyl-3(2H)-furanone (sweet), among others).

GC-MS analyses were done in a 5977A mass selective detector (Agilent Technologies Inc., Wilmington, DE, USA) coupled to the Agilent 7890B gas chromatograph, in electron impact ionization mode at 70 eV. Mass spectra were recorded in the range of 30 to 350 u. The SAFE extracts were analysed in a HP-FFAP (Agilent, 50 m x 0.25 mm i.d., 0.32 μm film thickness) column, using the same temperature program described for GC-O analyses. The volatile compound extracts were also analysed on a HP-5MS (Agilent, 30 m x 0.25 mm i.d., 0.25 μm film thickness) column under the following conditions: oven temperature was increased in three steps, first rate at 4°C/min from 50 °C until 160°C, second rate of 2.5°C/min until 220°C, and third at 8°C/min until 300°C, where finally was held for 4 min; injector temperature was 250°C; and Helium was used as carrier gas at 1 mL/min.

#### 2.5. Aroma extract dilution analysis (AEDA)

The AEDA method was applied to the SAFE extract of ripe lucuma fruit pulp, in order to establish the contribution of
each odour-active compound to the whole *P. lucuma* fruit aroma. Thus, this SAFE extract was diluted step by step to obtain 2^{th} dilutions (Schieberle, 1995), and each dilution was analysed by GC-O as it was above-mentioned. The odour activity of each compound was expressed as flavour dilution factor (FD), which was determined as the greatest dilution at which that compound was still detected by comparing all of the runs (Grosch, 1994).

### 2.6. Identification of odour-active volatiles

Odour-active volatile compounds were identified by comparing their mass spectra, retention indexes (RI) calculated using a C_{25}-alkane-mix (in both columns), and odour notes with those exhibited by the corresponding standards. The correlation of GC-O and GC-MS analyses was done by comparison of RI obtained in each run. The database NIST/EPA/NIH Mass Spectral Library 2014 (2.2) was used for the cases where the standards were not available.

### 2.7. Quantitation of key-aroma compounds

Internal standard (IS) method was used to quantitate the odour-active volatiles in both ripening stages. Ethyl cinnamate (98%, 50 µg, Alfa Aesar, Heysham, UK; 250 µg/kg fruit) was dissolved in dichloromethane (100 mL), and added to the homogenized fruits (300 g), separately for each stage, before extraction by SAFE distillation. To determine the response factor for each volatile compound, calibration lines were constructed using a series of solutions of varying nominal concentrations containing each analyte (IS: analyte, 1:5 until 5:1), where the slope was assumed as the response factor. IS was added to each solution in the same concentration to obtain the corresponding chromatograms (IOFL, 2011). Three replicates were made for each analyte. The comparison of GC-FID signals with those of standards was used to calculate the concentration of each analyte, according to the following equation:

\[ C_x = \frac{A_x}{A_{IS}} \times \frac{ug_{IS}}{kg_{run}} \times RF^{-1} \]

where \( C_x \) is the analyte concentration in µg/kg fruit, \( A_x \) is the analyte area, \( A_{IS} \) is the IS area, and \( RF \) is the response factor.

### 2.8. Statistical analyses

Data from the physicochemical characterization and quantitation of odour-active volatiles are reported as the mean ± standard deviation for determinations performed in triplicate. By the Statgraphics Centurion 18 – X64 software (StatPoint Technologies Inc. USA), T-tests for differences of means at probability level \( p \leq 0.05 \) were considered significant.

### 3. Results and discussion

Physicochemical characterization of unripe and ripe lucuma fruits is shown in Table 1. As it was expected, pH value and total soluble solid content increased with ripening, with significant differences among two stages. *Pouteria lucuma* fruits are climacteric that allows them to mature after harvesting, meaning that they have a living breathing system. One of the major chemical changes that is triggered during the fruit ripening is the flavour development, thus considering the volatile constituents as ripening products (Fischer & Scott, 1997).

The trained panellists described the orthonasal aroma of ripe *P. lucuma* fruit pulp as enriched in green, sweet, and rancid-fermented odour notes. The GC-O analyses of SAFE extract of this fruit showed the presence of 16 odour-active volatile compounds (Table 2) as contributors to the whole aroma. Different kind of chemical compounds were identified: C_{6}-compounds were responsible for the green, ketones for the sweet, esters for the fruity, and acids for the rancid odour notes.

AEDA analyses (Figure 2) showed that (Z)-3-hexenal, 4-hydroxy-4-methyl-2-pentanone, 2-methyl propanoic acid, 2,3-butanedione, (Z)-β-ocimene, methional, and hexanoic acid exhibited the highest FD values. In contrast, β-pinene (RI_{EPA/NIH} = 1024) and acetoin (RI_{EPA/NIH} = 1305) were detected as major constituents of SAFE extract did not contribute to the fruit aroma.

Quantitation of odour-active volatiles (Table 2) allowed to calculate odour-activity values (OAVs) and determine that 2,3-butanedione, methional, (Z)-3-hexenal, (E)-2-hexenal, (Z)-β-ocimene, and 3-methyl butanoic acid were the key-aroma compounds of *P. lucuma* fruit because they exhibited the highest OAV values (> 1). Diacetyl (2,3-butanedione) is a vicinal dike- tone with relatively low odour-threshold, which is used in flavour industry to impart butter odour-notes in dairy product, but it is considered as off-flavour in fermented beverages (lager-style beers and wines) if the concentration exceeds 10 mg L^{-1} (Gibson, Vidgren, Peddinti, & Krogerus, 2018; Li et al., 2018). It is noteworthy that the odour-note of 2,3-butanedione was described by the panellists as *lucuma*-like. (Z)-3-Hexenal and methional were almost not detected in GC-MS, but due to their low odour threshold, they exhibited high OAVs. During the post-harvest handling of this fruit, the rancid note is increased, suggesting a higher production of aliphatic acids (acetic, butanoic, 3-methyl butanoic, and hexanoic acids) that exhibit this characteristic odour-note.

The odour-active volatile compounds were detected and quantified in the SAFE extract of unripe *P. lucuma* fruits (Table 2), finding an increase in the amount of these compounds during ripening, with exception of 4-hydroxy-4-methyl-2-pentanone and 3-methyl butanoic acid. Some compounds, such as, methional, ethyl 3-hydroxy-butanoate, and butanoic acid, were only detected in ripe fruits. Figure 3 shows a comparison of odour-active volatile amount between the two ripening stages. The volatile compounds were grouped according to their chemical functions in C_{6}-compounds, ketones, terpenes, sulphur compounds,
| No. | Compound | Odor description | FFAP | HP-5 | Response Factor | Concentration ± SD (% CV) (μg kg⁻¹ fresh fruit) | OAV<sup>p</sup> |
|-----|----------|-----------------|------|------|----------------|-----------------------------------------------|--------|
| 1   | 2,3-Butanedione<sup>b</sup> | Sweet, butter, lucuma-like | 991  | 800  | 0.9442 | 425.3 ± 896.5 (21.1)<sup>a</sup> | 5.4<sup>g</sup> 1354 |
| 2   | (2)-3-Hexenal<sup>b</sup> | Green, grassy | 1148 | 800  | 0.9442 | 794 ± 7.5 (9.9)<sup>h</sup> | 164.2 ± 2.9 (1.8)<sup>h</sup> | 0.25<sup>f</sup> 657 |
| 3   | (E)-2-Hexenal<sup>b</sup> | Green, fruity | 1240 | 906  | 0.5471 | 1689 ± 2.47 (14.6)<sup>j</sup> | 16736 ± 554.1 (33.1)<sup>h</sup> | 17<sup>e</sup> 98 |
| 4   | (Z)-2-Ocimene<sup>b</sup> | Sweet, herbal | 1268 | 1023 | 0.9823 | 4220 ± 93.5 (22.1)<sup>j</sup> | 7788 ± 179.9 (23.1)<sup>h</sup> | 34<sup>c</sup> 23 |
| 5   | 4-Hydroxy-4-methyl-2-pentanone<sup>b</sup> | Minty, sweet | 1361 | 900  | 0.9343 | 2863.1 ± 303.2 (14.5)<sup>b</sup> | 20925.3 ± 303.2 (14.5)<sup>b</sup> | 64000<sup>g</sup> 0.03 |
| 6   | 2-Acetoxy-3-butanol<sup>b</sup> | Toasted, sweet | 1397 | 887  | 0.9220 | 75.3 ± 30.9 (31.4)<sup>j</sup> | – | – |
| 7   | Methional<sup>b</sup> | Cooked potato | 1432 | 926  | 0.9220 | 2440 ± 25.4 (10.4) | – | – |
| 8   | Acetic acid<sup>d</sup> | – | 1445 | 926  | 0.8678 | 218.9 ± 65.2 (29.7)<sup>j</sup> | 40452.9 ± 705.1 (1.7)<sup>b</sup> | 9900<sup>g</sup> 0.41 |
| 9   | 4-methyl-2-oxo-pentanoic acid<sup>d</sup> | Floral | 1487 | –    | –     | 218.9 ± 65.2 (29.7)<sup>j</sup> | 40452.9 ± 705.1 (1.7)<sup>b</sup> | 9900<sup>g</sup> 0.41 |
| 10  | Ethyl 3-hydroxy-butan-2-one<sup>b</sup> | Fresh, fruity | 1525 | <1000 | 0.9772 | 2251 ± 3.4 (1.5) | 14000<sup>g</sup> 0.02 |
| 11  | 2-Methyl-propanoic acid<sup>d</sup> | Plastic | 1571 | –    | 0.9153 | 98.3 ± 30.9 (31.4)<sup>j</sup> | 4698 ± 98.9 (21.0)<sup>b</sup> | 8100<sup>g</sup> 0.06 |
| 12  | Butanoic acid<sup>g</sup> | Rancid, butter | 1611 | –    | 0.9670 | 4686 ± 7.8 (1.7)<sup>j</sup> | 3100 ± 134.3 (43.3)<sup>h</sup> | 250<sup>c</sup> 1.24 |
| 13  | 3-Methyl butanoic acid<sup>g</sup> | Fruity, sweaty, toasted | 1659 | –    | 0.9670 | 100.4 ± 4.7 (4.7)<sup>j</sup> | 4096 ± 42.7 (10.4) | 300<sup>c</sup> 0.14 |
| 14  | Hexanoic acid<sup>d</sup> | Rancid, sweaty | 1853 | –    | 0.9278 | 99.2 ± 3.2 (3.2)<sup>j</sup> | 2316 ± 683 (29.6)<sup>b</sup> | 1300<sup>g</sup> 0.18 |
| 15  | (3E)-Hexenoic acid<sup>d</sup> | Green, rancid | 1952 | 999  | 0.9284 | 2316 ± 683 (29.6)<sup>b</sup> | 2316 ± 683 (29.6)<sup>b</sup> | 1300<sup>g</sup> 0.18 |
| 16  | Δ-3-Octalactone<sup>d</sup> | Coconut-like, creamy | 2009 | 1281 | 0.8868 | 2312 ± 6.2 (2.7) | – | – |

<sup>a</sup>Odors were numbered according to their retention time on FFAP column.

<sup>b</sup>Odorants were identified by comparing their retention indices on the FFAP and HP-5 column, their mass spectra, and their odour notes (detected by GC-O) with respective data of reference compounds.

<sup>c</sup>Odorants were identified by comparing their mass spectrum and/or retention indexes with literature data (database NIST/EPA/NIH Mass Spectral Library 2014 (2.2)).

<sup>d</sup>Odour note as perceived at the sniffing port during GC-O analysis.

<sup>e</sup>Retention index.

<sup>f</sup>All data are the mean of three measurements ± standard deviation. In all of the cases, correlation coefficient was higher than 0.975. Different letters (g, h) in a file means that there are significant differences based on Tukey test (p ≤ 0.05).

<sup>g</sup>Leffingwell and Associates (2008).

<sup>h</sup>Tamura, Boonbumrung, Yoshizawa, and Varanyanond (2001).

<sup>i</sup>PubChem Open Chemistry Database (2019).

<sup>j</sup>Lytra, Cameleyre, Tempere, and Barbe (2015).

<sup>k</sup>Czerny et al. (2008).

<sup>l</sup>Lytra, Cameleyre, Tempere, & Barbe (2015).

<sup>m</sup>Buttery, Teranishi, Ling, and Turnbaugh (1990).

<sup>n</sup>Kishimoto, Wanikawa, Kono, and Shibata (2006).

<sup>o</sup>OAV = Odour Activity Value, concentration of volatile compounds in ripe fruit divided by their odour threshold.

<sup>p</sup>Not determined.

<sup>q</sup>Los odorantes se enumeraron de acuerdo con su tiempo de retención en columna FFAP.

<sup>r</sup>Los odorantes se identificaron por comparación de sus índices de retención en columnas FFAP y HP-5, sus espectros de masas y sus notas de olor (detectadas por GC-O), con los respectivos de compuestos de referencia.

<sup>s</sup>Los odorantes se identificaron por comparación de sus espectros de masas y/o índices de retención con los datos reportados en la literatura (base de datos NIST/EPA/NIH Mass Spectral Library 2014 (2.2)).

<sup>t</sup>Nota de olor percibida en el puerto de olfacción durante los análisis por GC-O.

<sup>u</sup>Indice de retención.

<sup>v</sup>Todos los datos son el promedio de tres medidas ± desviación estándar. En todos los casos, el coeficiente de correlación fue mayor que 0.975. Letras diferentes (g, h) en una fila significa que existen diferencias significativas basadas en la prueba de Tukey (p ≤ 0.05).

<sup>w</sup>Leffingwell & Associates, (2008).

<sup>x</sup>Buttery, Teranishi, Ling, & Turnbaugh (1990).

<sup>y</sup>Kishimoto, Wanikawa, Kono, & Shibata (2006).

<sup>z</sup>OAV = Odour Activity Value, concentración de un compuesto volátil en la fruta madura, dividido por su valor umbral de olor.

<sup{p}Not determined.
aliphatic acids, and esters. With exception of ketones, the other volatile compounds were found in significant major amount in the ripe stage of lucuma fruit, indicating that their biogenesis is activated during this process. Ketones are responsible for sweet, \( C_6 \)-compounds for green, and aliphatic acids for rancid characteristic odour notes in this fruit. The unsaturated lineal and branched aliphatic acids are ripening products which are developed through two biogenetic ways: \( \beta \)-oxidation pathway from fatty acids, and amino-acid metabolism, respectively (Fischer & Scott, 1997).

Aroma-active volatile compounds have been studied in other fruits belonging to Sapotaceae family. Based on their odour activity values (OAVs), (E)-3-penten-2-one, (E)-\( \beta \)-caryophyllene, methional, 3-methylbutanal, 3-heptanone, butanal, and 3-hexanone were found the most important aroma volatiles in *Lucuma hypoglauca* from Mexico (Pino, Moo-Huchin, Sosa-Moguel, Sauri-Duch, & Cuevas-Glory, 2017); (E)-cinnamaldehyde, 3-methylbutanal, limonene, (Z)-\( \beta \)-ocimene, linalool, methyl (E)-cinnamate, and \( \beta \)-caryophyllene in *Diospyros digyna* Jacq. from

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**Figure 2.** GC and AEDA analyses on FFAP column of odour-active compounds from *Pouteria lucuma* ripe fruit obtained by SAFE extract. Peak numbers correspond to the compound numbers in Table 2.

**Figura 2.** Análisis por CG y AEDA en columna FFAP de los compuestos activos olfativamente en la fruta madura de *Pouteria lucuma* obtenidos a partir del extracto SAFE. Los números de los picos corresponden con los números de los compuestos en la Tabla 2.

**Figure 3.** Odour-active compound amount in unripe and ripe *Pouteria lucuma* fruits. Different letters in amount of each kind of compounds means significant differences (\( p \leq 0.05 \)) among two ripening stages.

**Figura 3.** Cantidad de compuestos activos olfativamente en frutas inmaduras y maduras de *Pouteria lucuma*. Letras diferentes en la cantidad de cada clase de compuestos indica que hay diferencias significativas (\( p \leq 0.05 \)) entre los dos estados de madurez.
The active volatile compounds of *P. lucuma* fruit were identified, suggesting that green, sweet, and rancid odour-notes are predominant in this fruit. The significance of ketones, sulphur, and C6-aliphatic compounds on the aroma of lucuma were reported, confirming that methional, (Z)-3-hexenal, (E)-2-hexenal, and (Z)-β-ocimene are key odour compounds in fruits of Sapotaceae family. The ripening process of this fruit triggered the production of volatile compounds, with emphasis on the C6-compound and aliphatic acid amount. These results are important to improve the processing of this fruit in order to preserve its authentic aroma.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

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**References**

AOAC. (2006). *Official methods of analysis of AOAC international* (18th ed.). Gaithersburg, MD: Association of Official Analytical Chemists.

Buttery, R. G., Teranishi, R., Ling, L. C., & Turnbaugh, J. G. (1990). Quantitative and sensory studies on tomato paste volatiles. *Journal of Agricultural and Food Chemistry*, 38, 336–340.

Czerny, M., Christlbauer, M., Christlbauer, M., Fischer, A., Granvogl, M., Hammer, M., ... Schieberle, P. (2008). Re-investigation on odour thresholds of key food aroma compounds and development of an aroma language based on odour qualities of defined aqueous odrorant solutions. *European Food Research Technology*, 228, 265–273.

da Silva, B. A., Gordon, A., Jungfer, E., Marx, F., & Maia, J. G. S. (2012). Antioxidant capacity and phenolics of *Pouteria macrophylla*, an under-utilized fruit from Brazilian Amazon. *European Food Research Technology*, 234, 761–768.

da Silva Pinto, M., Galvez Ranilla, L., Apostolidis, L., Lajolo, F. M., Genovese, M. I., & Shetty, K. (2009). Evaluation of antihyperglycemia and antihypertension potential of native peruvian fruits using in vitro models. *Journal of Medicinal Food*, 12, 278–291.

Engel, W., Bahr, W., & Schieberle, P. (1999). Solvent assisted flavour evaporation – A new and versatile technique for the careful and direct isolation of aroma compounds from complex food matrices. *European Food Research Technology*, 209, 237–241.

Erazo, S., Escobar, A., Olaeta, J., & Undurraga, P. (1999). Determinación proximal y carotenoides de frutos de seis selecciones de lucuma (*Pouteria lucuma*). *Alimentos*, 24, 67–75.

Fischer, C., & Scott, T. R. (1997). *Food flavours, biology and chemistry* (pp. 25–26). Cambridge, UK: The Royal Society of Chemistry.

Fuentealba, C., Galvez, L., Cobos, A., Olaeta, J. A., Defilippi, B. G., Chininos, R., ... Pedreschi, R. (2016). Characterization of main primary and secondary metabolites and *in vitro* antioxidant and antihyperglycemic properties in the mesocarp of three biotypes of *Pouteria lucuma*. *Food Chemistry*, 190, 403–411.

Gibson, B., Vidgren, V., Peddinti, G., & Krogerus, K. (2018). Diacetyl control during brewery fermentation via adaptive laboratory engineering of the larger yeast *Saccharomyces pastorianus*. *Journal of Industrial Microbiology & Biotechnology*, 45, 1103–1112.

Grosch, W. (1994). Determination of potent odourants in food by aroma extract dilution analysis (AEDA) and calculation of odour activity values (OAVs). *Flavour and Fragrance Journal*, 9, 147–158.

IOfI, Working Group on Methods of Analysis. (2011). Guidelines for the quantitative gas chromatography of volatile flavouring substances, from the Working Group on Methods of Analysis of the International Organization of the Flavor Industry (IOFI). *Flavour and Fragrance Journal*, 26, 297–299.

Kishimoto, T., Wanikawa, K., Kono, K., & Shibata, K. (2006). Comparison of the odor-active compounds in unhopped beer and beers hopped with different hop varieties. *Journal of Agricultural and Food Chemistry*, 54, 8855–8861.

Lasekan, O., & Peng Yap, S. (2018). Characterization of the aroma compounds in fresh and dried sapodilla (*Manikara zapota*, L) by the application of aroma extract dilution analysis. CYTA-Journal of Food, 16, 801–806.

Leffingwell & Associates. (2008). *Odor & flavor detection thresholds in water* (In parts per billion). Retrieved from [http://www.leffingwell.com/odorthreshold.htm](http://www.leffingwell.com/odorthreshold.htm).

Li, P., Gao, Y., Wang, C., Zhang, C.-Y., Guo, X., & Xiao, D. (2018). Effect of ILV6 deletion and expression of aldB from *Lactobacillus plantarum* in *Saccharomyces uvarum* on diacetyl production and wine flavor. *Journal of Agricultural and Food Chemistry*, 15, 8556–8565.

Lytra, G., Cameleyre, M., Tempere, S., & Barbe, J.-C. (2015). DISTRIBUTION and organoleptic impact of ethyl 3-hydroxybutanoate enantiomers in wine. *Journal of Agricultural and Food Chemistry*, 63, 10484–10491.

Martin, D. A., & Osorio, C. (2019). Identification of aroma-active compounds in *Pouteria sapota* fruit by aroma extraction dilution analyses (AEDA). *Quimica Nova*. In press.

Ministerio de Agricultura del Perú (Minagri). (2019a). Lucuma. Retrieved from [http://minagri.gob.pe/portal/download/pdf/sektoragrario/agricola/lneasdecultivosemergentes/LUCUMA.pdf](http://minagri.gob.pe/portal/download/pdf/sektoragrario/agricola/lneasdecultivosemergentes/LUCUMA.pdf).

Ministerio de Agricultura del Perú (Minagri). (2019b). Serie Estadística de Producción Agrícola (SEPA). Retrieved from [http://frenteweb.minagri.gob.pe/sisca/?mod=consulta_cult](http://frenteweb.minagri.gob.pe/sisca/?mod=consulta_cult).

Ministerio de Salud del Perú. (2009). Tablas Peruanas de Composición de Alimentos. Retrieved from [http://www.ins.gob.pe/insvirtual/images/otropubs/pdf/Talb%20de%20Alimentos.pdf](http://www.ins.gob.pe/insvirtual/images/otropubs/pdf/Talb%20de%20Alimentos.pdf).

Pino, J., Moo-Huchin, V., Sosa-Moquiel, O., Sauri-Duch, E., & Cuevas-Glory, L. (2017). Characterization of aroma-active compounds in choclo (Lucuma hypoglauca Standley) fruit. *International Journal of Food Properties*, 20, 5444–5448.
Pino, J. A., Ortiz-Vazquez, E., Sauri-Duch, E., & Cuevas-Glory, L. (2014). Characterization of aroma-active compounds in black sapote (*Diospyros digyna* Jacq.). *Acta Alimentaria*, 43, 547–552.

PubChem Open Chemistry Database. (2019). Retrieved from https://pubchem.ncbi.nlm.nih.gov

Schieberle, P. (1995). New developments in methods for analysis of volatile flavor compounds and their precursors. In A. G. Gaonkar (Ed.), *Characterization of food: Emerging methods* (pp. 403–431). Amsterdam, The Netherlands: Elsevier.

Schieberle, P., & Hofmann, T. (2011). Mapping the combinatorial code of food flavors by means of molecular sensory science approach. In H. Jelen (Ed.), *Chemical and functional properties of food components series. Food flavors. Chemical, sensory and technological properties* (pp. 413–438). Boca Raton, FL: CRC Press.

SiICEX, Sistema Integrado de Información de Comercio Exterior, Lima. (2019). Retrieved from http://www.siicex.gob.pe/siicex/portal5ES.asp?_page_=160.0000

Taiti, C., Colzi, I., Azzarello, E., & Mancuso, S. (2017). Discovering a volatile organic compound fingerprinting of *Pouteria lucuma* fruits. *Fruits*, 72, 131–138.

Tamura, H., Boonbumrung, S., Yoshizawa, T., & Varanyanond, W. (2001). The volatile constituents in the peel and pulp of a green Thai mango, Khieo Sawoei cultivar (*Mangifera indica* L.). *Food Science and Technology Research*, 7, 72–77.

Yahia, E. M., & Gutierrez-Orozco, F. (2011). Lucuma (*Pouteria lucuma* (Ruiz and Pav.) Kuntze). In E. M. Yahia (Ed.), *Postharvest biology and technology of tropical and subtropical fruits* (pp. 443–450e). Cambridge, UK: Woodhead Publishing.