Phenolic profile and antioxidant capacity of fruit *Averrhoa carambola L.*: a review

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Abstract

The fruit of *Averrhoa carambola L.* (*A. carambola L.*) belongs to the Oxalidaceae family, is probably native to Ceylon and Moluccas, and is commonly known in various places as “star-fruit” or “carambola.” This fruit is used as traditional medicine for a variety of diseases. The phenolic compounds that the fruit contains are thought to be responsible for its many benefits. Currently there is extensive research on the content of phenolic compounds and the antioxidant capacity of the fruit of *A. carambola L.* Most authors report total phenolic content (TPC) and total flavonoid content (TFC); while antioxidant capacity has been analyzed using different techniques such as: 1,1-diphenyl-2-picrylhydrazyl assay (DPPH), ferric reducing antioxidant power assay (FRAP), and 2,2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS). HPLC analysis has resulted in the identification of phenolic compounds in the fruit. However, each of the authors use different methodologies in the various stages of the analysis, from obtaining the sample to the form of analysis, and this may explain the differences in their results. This paper offers a review of existing research on the phenolic profile and antioxidant capacity of the *A. carambola L.* fruit, with special attention to the methodologies used.

Keywords: *A. carambola L.*; extraction; antioxidant capacity; phenolic compounds; HPLC.

Practical Application: The manuscript analyzes the methods of extraction and quantification of phenolic compounds from the fruit of *Averrhoa carambola L.* in different studies. This presents great interest in the area of biotechnology and food science.

1 Introduction

Since ancient times, human begins have relied on certain plants or herbs to treat the diseases that afflict them. This ancient knowledge has recently gained considerable interest in the pharmaceutical community (Dasgupta et al., 2013). One reason is that nearly 80% of the world’s population in developing countries use traditional remedies (Lee et al., 2019), many of them based on the empirical knowledge, popular tradition, beliefs and culture of their society (Payal et al., 2012). Some foods, in addition to their nutritional characteristics, contain other bioactive compounds that can help maintain optimal health conditions, reducing the risk of non-communicable diseases such as diabetes, cancer, dyslipidemias and cardiovascular diseases. These foods are known as functional foods, and they must go through clinical trials that document the beneficial properties for the body. In some cases, these claims are regulated by certain government agencies such as the Food and Drug Administration (FDA), the Brazilian Agency for Sanitary Regulation (ANVISA), and others (Granato et al., 2020). In recent years, various groups of scientists have begun to analyze the composition of such plants and fruits, focusing on minority compounds—mainly phenolic compounds and their antioxidant capacity—which have been attributed with preventive and treatment effects against various chronic diseases (Lin et al., 2016). Phenolic compounds are secondary metabolites of plants that have protective functions against biotic and abiotic stress factors (Li et al., 2018). Their chemical structure is made up of one or more hydroxyl constituents attached to an aromatic ring, and according to their structure, they are divided into phenolic acids, simple phenols, flavonoids, coumarins, lignans and tannins (Valduga et al., 2019). *Averrhoa carambola L.* (*A. carambola L.*) is cultivated in India as an edible fruits and is also used for the treatment of various diseases (Thomas et al., 2008). There is currently a wide range of research available on phenolic compounds and antioxidant capacity of different plants. The results vary, however, and among the possible explanations are the many different methods for collecting and processing samples, the use of solvents and the form of expression of the results (Vargas-Madriz et al., 2020). The present work is an exhaustive review of the scientific literature on the phenolic profile and antioxidant capacity of the fruit of *A. carambola L.* with special attention to methods used.

2 *A. carambola L.*

The genus *Averrhoa* contains several species, among which is *A. carambola L.*, known as star-fruit or carambola. It belongs to the Oxalidaceae family, a perennial tree native to tropical and subtropical places. It is thought to be native to Ceylon and Moluccas (Kurup & Mini, 2017; Manda et al., 2012; Payal et al., 2012). It is cultivated in Southeast Asia and Malaysia, southern China, Taiwan and India, reported in the Philippines, Queensland, Australia and in some parts of the Pacific; the fruit is available from March to August (Dembitsky et al., 2011; Payal et al., 2012).
This fruit is considered ideal for its nutritional value in macro and micro nutrients (Tables 1 and 2). The skin of the immature fruit is green, and as it matures, it becomes yellow. The fruit is usually oblong with a tart-sweet flavor. In cross section, the fruit resembles a star shape, hence its name. It is used traditionally for treating fever, eye problems, kidney and bladder issues, and indigestion. Various scientific studies have been carried out on this fruit to determine its hypoglycemic power, anti-inflammatory activity, antimicrobial activity, anti-ulcer effect and antioxidant activity (Manda et al., 2012; Muthu et al., 2016; Payal et al., 2012). A current study by Pothasak et al. (2020) reported that an extract of A. carambola L. has an anti-inflammatory effect on macrophage cells. However, there is a need for clinical studies to evaluate the possible effect of phenolic compounds that have been detected in the fruit of A. carambola L. on human health (Dionisio et al., 2020a, b).

3 Sample treatment before extraction

The treatment of the samples collected prior to extraction is essential when analyzing the compounds of interest from the plants. The different treatments reported by the authors who analyze the phenolic compounds and the antioxidant capacity of A. carambola L. are described in Table 3.

In most of the studies analyzed, the sample was collected in local markets, taking as inclusion criteria: the physical uniformity of the samples, the state of maturity, the color and size, and that no visible damage is observed in the fruits. Once obtained, they were washed (some authors report cutting the sample into small pieces to facilitate homogenization in a blender or using a mortar). They then analyzed the fresh and dry samples (Shofian et al., 2011; Thomas et al., 2016). Other authors, after homogenizing the sample in a blender, centrifuged and filtered the sample (Shui & Leong, 2004). Still others use liquid nitrogen to grind the samples (Lim & Lee, 2013). Drying methods included shade-drying, sun-drying (Chauhan & Kapfo, 2016; Verma et al., 2018) drying at room temperature (Batiston et al., 2013), by means of a hot air oven (Abdullah & Noriham, 2014; Pothasak et al., 2020; Rahman et al., 2016; Ruveni et al., 2017) by means of a dehydrator, and freeze drying (lyophilization) (Guevara et al., 2019; Shofian et al., 2011; Shui & Leong, 2006; Yan et al., 2013; Zainudin et al., 2014). Conventional methods are regularly used for their simplicity and low cost, but they involve high temperatures, some light exposure, and long times. The drying temperatures reported in the different investigations range from 40 to 65 °C, which is appropriate for avoiding degradation of compounds. Drying time is another important factor, and in these studies varies from a few hours to a few days. It has been observed that the appropriate combination of time and temperature deactivates of the polyphenol oxidase enzyme and eliminates microorganisms that degrade phenolic compounds. An improper drying process can cause oxidation reactions and degradation of components of interest (Teles et al., 2018). The freeze-drying (lyophilization) method is used in various studies for its effectiveness, obtaining greater porosity in the samples, decreased degradation of bioactive compounds, and a relatively short period of time to dry samples. The disadvantages of this method is its high cost and difficulty unskilled personnel have in handling the equipment (Gaidhani et al., 2016). After drying, some authors mention homogenizing the sample in a mill or in a blender. The particle size of the sample was not mentioned. Preferably, particle size should less than 0.5 mm in diameter in order to obtain an adequate contact surface with the solvent, favoring the extraction process (Pătrăuţanu et al., 2019). All the variables mentioned in the sample treatment, prior to the extraction process, are essential to avoid degrading phenolic compounds and decreasing antioxidant capacity (Makanjuola, 2017).

4 Extractions of phenolic compounds from the fruit A. carambola L. with different solvents

Table 3 summarizes the various methods used in the extraction process of A. carambola L. compounds, separated by type of solvent: water, ethanol, methanol, acetone, diethyl ether, in different proportions.

4.1 Water extraction

After sample treatment, Shui & Leong (2004) mixed the solid residue of the sample in a 50% (v/v) aqueous acetone solution, at 90 °C for 45 min. The extract was then concentrated using a rotary evaporator and stored at -18 °C. Annegowda et al. (2012) extracted the plant sample in an ultrasonicator (42 kHz, 135 W; Branson ultrasonic corporation, USA) using a solid/solvent ratio of 1:10 (w/v) at 25 ± 1 °C and at different extraction times: 15, 30, 45 and 60 minutes, under low light conditions. After the extraction time had elapsed, the residue was re-extracted.
Table 3. Studies that have reported the compositional analysis of *A. carambola* L. fruits.

| Sample treatment | Solvent/extraction process | Reference |
|------------------|----------------------------|-----------|
| Water extraction | The sample was homogenized in a blender, centrifuged, and vacuum filtered. The solid residue was mixed with 50% (v/v) water/acetone at 90 °C for 45 min, then evaporated under reduced pressure and filled with water to a certain volume, and stored at -18 °C. | Shui & Leong (2004) |
| All the sample had uniform color, maturation time and size. The sample was washed with tap water followed by distilled water, then homogenized in a blender. 25 g of sample was mixed in water at a ratio of 1:10 (w/v). An ultrasonicator was used in low light conditions at different times (15, 30, 45, 60 min) at 25 ± 1 °C. The residues were dissolved in the same ratio mentioned. The extracts were filtered (Whatman No. 1) and concentrated in a rotary evaporator, and finally the concentrate was lyophilized. | Annegowda et al. (2012) |
| The vegetable sample was obtained from tart-type and honey-type *A. carambola* L., classified in two maturity stages: 3 and 4. The sample was washed with running water and dried in an oven, then later ground. 20 g were placed in 600 mL of boiling water at a ratio of 1:30 (w/v), subsequently filtered (Whatman No.4) and the extract concentrated using a rotary evaporator at 70 °C. The sample was stored at 4 °C. | Abdullah & Noriham (2014) |
| The sample was washed and cut into small parts. 100 g were placed in 200 mL of water at a 1:2 (w/v) ratio. It was then immersed in a 40 °C water bath and after 24 h the extract was filtered through filter paper and evaporated at 40 °C. The concentrate was stored at 4 °C. | Khanam et al. (2015) |
| The sample was chosen from fruit not too mature or damaged; it was cut into uniform size. A part of the sample (5 kg) was stored in the shade and another dried in the sun for 4 days, then it was milled in a blender. The other part of the sample was used fresh. 200 g DM and 2,000 g FM were placed in 500 and 5,000 mL at a ratio of 2:5 (w/v) in water/acetone at 60% (v/v). The mixture was stirred for 3 h at room temperature, then the extracts filtered and evaporated. The aqueous portion was dried in a hot air oven at 50 °C. | Chauhan & Kapfo (2016) |
| Extraction using ethanol and mix polar solvents | 25 mL of 50% (v/v) ethanol was added to a sample using a 1:10 (w/v) ratio. The sample was sonic and mixed in a vortex for 60 s. The extract was centrifuged at 2,000 g for 5 min at room temperature and finally filtered. | Leong & Shui (2002) |
| Whole samples weighing between 10 and 30 g (including peel) were crushed for 1 min using a blender then homogenized in a mortar. The sample was mixed in 100 mL of 50% (v/v) ethanol with stirring for 10 min and was subsequently filtered. The supernatant was used for analysis, it was stored at -20 °C. | Lim et al. (2007) |
| NR | The sample was mixed with 60% (v/v) ethanol. The extract was concentrated by means of a rotary evaporator. | Muñoz-Jáuregui et al. (2007) |
| NR | 4 g in 8 mL of 50% (v/v) ethanol at a ratio of 1:2 (w/v), at room temperature for 30 min with occasional stirring, then the extract was centrifuged at 2,000 xg for 15 min. | Ali et al. (2010) |
| The samples were washed with running water and the ends of the fruit removed. It was then cut into uniform pieces and homogenized in a blender for 2 min. Subsequently it was stored at -80 °C and lyophilized for 3 days, then the sample was ground through a fine mesh and stored at -20 °C. 2 g in 50 mL of ethanol 70% (v/v) at a ratio of 1:25 (w/v), stirring at 200 rpm for 120 min at 50 °C. The mixture was centrifuged at 3,000 rpm for 15 min at room temperature and the supernatant was stored at -20 °C. | Yan et al. (2013) |
| The samples were selected for uniformity in size, color, maturation stage and without any damage. They were washed, their peel was removed manually and cut into small parts. 100 g in 200 mL of ethanol at a ratio of 1:2 (w/v), it was immersed in a water bath at 40 °C and after 24 h the extract was filtered and evaporated at 40 °C. The concentrate was stored at 4 °C. | Khanam et al. (2015) |
| Ripe samples were obtained and a juice prepared using a domestic juice processor. The resulting pomace was dried at 50 °C for 12 h, then ground and stored at -20 °C. The sample was mixed in acidified ethanol (1% 1N hydrochloric acid, pH 3.0) at a ratio of 1:10 (w/v) at different temperatures (18, 25, 40, 55, 61 °C) and concentrations of solvents (43, 50, 65, 80, 86%). The extracts stirred for 3 h. They were then spun at 3,000 rpm for 15 min. | Saikia et al. (2015) |

DM: dry matter; FM: fresh matter; NR: not reported. Results presented as reported by the authors.
Phenolic profile of Averrhoa carambola L.

Table 3. Continued...

| Sample treatment | Solvent/extraction process | Reference |
|------------------|----------------------------|-----------|
| The collection was carried out twice. The samples obtained were in the same stage of maturation and without any damage. The samples were cut into small pieces to be lyophilized and ground, then stored at -20 °C. | A hydroalcoholic extraction was performed (the relationship is not reported). | Guevara et al. (2019) |
| Extraction using methanol and mix polar solvents | | |
| The sample was cut and frozen with liquid nitrogen, it was stored at −20 °C prior to extraction. | 20 g of sample was placed in 80 mL of 100% (v/v) methanol at a ratio of 1:4 (w/v), mixed in a blender for 1 min and subsequently filtered. The residue from the extract was re-extracted and filtered. Finally the extracts were concentrated in a rotary evaporator at 40 °C. | Mahattanatawee et al. (2006) |
| The samples were selected for uniformity in texture, size and color; They were washed with distilled water and the sample subsequently homogenized by means of a kitchen mixer for 3 min. The vegetable sample was exposed to UV light at different times from 0 to 60 min. | A ratio of 1:10 (w/v) was used, extraction was carried out with stirring at 1,100 rpm for 3 h at 25 ± 1 °C. Subsequently, it was filtered (Whatman No. 1) at 300 g for 15 min and the supernatant was concentrated by means of a rotary evaporator at 50 °C. Finally it was lyophilized and stored at 4 °C. | Bhat et al. (2011) |
| A part of the sample was cut for analysis while fresh, and the other part of the sample was lyophilized for 3 days. | The extraction was carried out by means of a stirrer in a water bath at 40 °C for 1 h. Filtered and evaporated at a temperature of 40 °C. | Shofian et al. (2011) |
| The samples were selected for uniformity in texture, size, color, maturity and without apparent damage from microorganisms. They were washed with running water followed by distilled water 2 to 3 times. | 25 g of sample was mixed with distilled water and methanol in a ratio of 1:10 (w/v) in a kitchen blender. Then they were sonicated at different times (15, 30, 45, 60 min) at 25 ± 1 °C and in low light. The residues were dissolved in the same ratio until the extract was clarified. The extract was then filtered (Whatman No. 1) and concentrated in a rotary evaporator and finally lyophilized. | Annegowda et al. (2012) |
| The samples were collected in their mature stage, washed with running water, cut and liquefied for 2 min. | 10 g of sample was placed in 40 mL of methanol at a ratio of 1:4 (w/v) using an orbital shaker, then filtered through filter paper. The residue was re-extracted and filtered. | Murillo et al. (2012) |
| The samples were obtained in the mature stage and stored at 5 °C, and only those with no visible damage were analyzed. The sample was washed at room temperature and cut into 2 × 2 cm pieces, then stored in polypropylene boxes with transparent lids. Two treatments were performed: one group was stored in the dark and the other group under fluorescent light, both treatments were exposed to UV light at different times from 0 to 60 min. | The vegetable sample was extracted at a ratio of 1:3 (w/v) for 1 h at 40 ± 1 °C, then filtered through filter paper (Whatman No. 1) and the supernatant was re-extracted with fresh solvent following the above procedure. Subsequently, the extract was concentrated in a rotary evaporator. | Zainudin et al. (2012) |
| The samples were collected during three consecutive weeks, washed with deionized water and dried at room temperature, and then ground. | The samples were mixed with methanol at a ratio of 1:10 (w/v), stirring for 4 h under low light. The extract was filtered and concentrated by a rotary evaporator. | Batiston et al. (2013) |
| Ripe and immature samples were collected and peeled manually, and the samples were ground using liquid nitrogen and stored at -80 °C. | 5 g of sample was placed in 50 mL of 80% (v/v) methanol at a ratio of 1:10 (w/v), using an orbital shaker at 150 rpm for 2 h at room temperature. The extract was filtered (Whatman No. 1) and evaporated at 45 °C for 1 h. The concentrate was re-dissolved in 5 mL of 80% (v/v) methanol and stored at −80 °C. | Lim & Lee (2013) |
| The samples were obtained in the mature stage, washed and cut into cubes, after which they were lyophilized and ground. | The lyophilized samples were consecutively extracted with 100% methanol (v/v) in 1:10 (w/v) ratio for 1 h. They were subsequently filtered and evaporated by means of a rotary evaporator. The extracts were stored in airtight bottles and rinsed with nitrogen gas. They were then stored at −20 ± 1 °C. | Zainudin et al. (2014) |
| The samples obtained were stored at 4 °C. 50 g of fruit were cut into small pieces. | 50 g of sample was placed in 80% (v/v) methanol at a ratio of 1:3 (w/v) with stirring for 24 h at room temperature. The extract was filtered and then centrifuged at 8,000 rpm for 15 min and the supernatant was used for subsequent analyzes. | Adiyaman et al. (2016) |

DM: dry matter; FM: fresh matter; NR: not reported. Results presented as reported by the authors.
### Table 3. Continued...

| Sample treatment | Solvent/extraction process | Reference |
|------------------|----------------------------|-----------|
| The samples were washed with tap water and kept outdoors for a few hours. The fruit was then manually peeled using a peeler, cut into small pieces, and oven dried at 40 °C for 14 days. | 10 g of sample was mixed for 1 h in 70% (v/v) methanol using a shaker, then filtered through Whatman paper and re-extracted twice using new solvent. The 3 extracts were concentrated in a rotary evaporator at 40 °C. | Rahman et al. (2016) |
| The samples were obtained in the semi-mature to mature stage. | 2 g of sample was mixed in 50 mL of 80% (v/v) methanol for 5 min. The extract was then filtered and stored in dark bottles at 4 °C. | Recuenco & Lacsamana (2016) |
| The samples were washed and dried in the shade. They were then pulverized in an electric mill with a mesh size of 60. | A soxhlet apparatus was used for the extraction. First the sample was defatted with 250 mL of 98% petroleum ether for 6 h, then 250 mL of chloroform were used for 9 h and finally 250 mL of methanol. The extract was filtered (Whatman No. 1) and concentrated in a rotary evaporator at 40 °C. | Verma et al. (2018) |
| Extraction using acetone | 100 g of fresh sample was mixed with acetone/water 70:30 (v/v) by means of a blender for 24 h at 4 °C. It was then filtered and the residue mixed with absolute methanol, leaving it to macerate for 24 h at 4 °C. Acetone was removed by vacuum filtration at 37 °C and the aqueous residue was washed with dichloromethane. The extract was concentrated under vacuum at 37 °C. The concentrated extract was divided into two parts. One was lyophilized and re-dissolved in methanol in a ratio of 1: 5 (v/v) which was used for the quantitative analysis of phenolic compounds. The second part was used to determine antioxidant activity. | Luximon-Ramma et al. (2003) |
| NR | Different proportions of mixtures of solvents water/acetone and water/ethanol (0, 30, 50, 70, 100%) were used, as well as temperatures: 30, 50, 70, 90 °C and extraction times: 15, 30, 45, 60 min. | Shui & Leong (2006) |
| The samples were homogenized in a blender, then centrifuged and filtered. The liquid portion (juice) was used directly for the total antioxidant capacity and phenolic. The solid portion (residue) was dried in a lyophilizer. | For the extraction of free phenolic compounds, 25 g was mixed in 80 ml 80% acetone for 5 min. Subsequently, the extract was centrifuged at 2,500 g for 10 min. The entire process was carried out twice. The supernatants obtained were combined and filtered through No. 1 filter paper, the extract was concentrated at 45 °C and stored at -45 °C. | Pang et al. (2016) |
| The samples were obtained from four cultivars: Hong from Zhanjiang; Taiguo from Guangzhou Park; Honglong and Xiangmi from Huazhou; and Shantou from cities in Guangdong province. They were chosen with the same degree of maturity and stored at -20 °C. | For the extraction of bound phenolic compounds, the residues from the previous extraction were digested for 90 min, stirring at room temperature using 50 mL of sodium hydroxide together with a stream of nitrogen. The digested sample was acidified with hydrochloric acid (pH 2) and extracted five times with ethyl acetate, followed by contraction of the extract in a rotary evaporator at 45 °C. The rotavaporated extracts were diluted with 5 mL of distilled water and stored at 40 °C. | Pang et al. (2016) |
| Extraction using diethyl ether | 20 mL of diethyl ether was used and the remaining solution was stored at -20 °C for one day. It was subsequently centrifuged at 9,000 rpm for 10 min, the supernatant transferred to a separating funnel and 3 extractions were made with 20 mL of this solvent. Anhydrous sodium sulfate (spatula tip) was added to the organic extract, then filtered and passed through a rotary evaporator at 30 °C. The extract was mixed with methanol/water (1:1) and then filtered through a 0.20 µm membrane and analyzed by chromatography. | Esteban Muñoz et al. (2018) |

DM: dry matter; FM: fresh matter; NR: not reported. Results presented as reported by the authors.
with 100 mL of the solvent until obtaining a crystalline extract. Subsequently, the extracts were filtered through filter paper, and concentrated in a rotary evaporator at 70 °C. The concentrated extracts were then lyophilized and stored in hermetic containers at 4 °C. These authors carried out the same procedure with the methanolic extract. Khanam et al. (2015) used a solid solvent ratio of 1:2 (w/v) in a water bath for 24 h. Subsequently, the extractant solution was filtered through filter paper and concentrated under reduced pressure in a rotary evaporator at 40 °C. Finally, the extract was stored at 4 °C. This procedure was also used in preparing the ethanolic extract. Abdullah & Noriham (2014) on the other hand, used a ratio of 1:30 (w/v) and an extraction time of 10 min. Subsequently, the extract was filtered through filter paper and concentrated in a rotary evaporator at 70 °C, and finally the concentrated extract was stored at 4 °C in amber bottles. Chauhan & Kapfo (2016) performed two extractions: in the first they mixed 200 g of a sun-dried sample in 500 mL of 60% (v/v) water (water/acetone). In the second extraction, they mixed 2,000 g of shade-dried sample in 5,000 mL of 60% (v/v) water (water/acetone). Both solutions were stirred for 3 h at room temperature (30 °C) then filtered and the solvent consequently removed in a rotary evaporator. The dry residue of the extracts was collected and used for the antioxidant capacity tests.

### 4.2 Extraction using ethanol and mixed polar solvents

In the study by Leong & Shui (2002) prior to extraction, the authors homogenized the sample in a blender. This sample was placed in a centrifuge tube in which 25 mL of 50% (v/v) hydro-alcoholic solvent (HPLC grade water) with a 1:10 (w/v) ratio has been added. The extraction was performed by a sonicator; it was also mixed by vortex for 60 s. The extract was then centrifuged at 2,000 g for 5 min at room temperature, and finally filtered. Lim et al. (2007) mentioned that after homogenization, the sample was mixed in 100 mL of 50% (v/v) hydro-alcoholic solvent with manual agitation or with vibration for 10 min. After the extract was vacuum filtered and centrifuged, the supernatant was finally stored at -20 °C. Muñoz-Jáuregui et al. (2007) mentioned extraction of the fresh sample with 60% (v/v) ethanol followed by evaporation of the solvent in a rotary evaporator. But they did not refer to the solid/solvent ratio or the process for purifying the extract. Ali et al. (2010) performed their extraction using a 1:2 (w/v) ratio with 50% (v/v) ethanol at room temperature for 30 min and with occasional stirring. The extract was then centrifuged at 2,000 g for 15 min and the supernatant used for the analyses. Yan et al. (2013) used a ratio of 1:25 (w/v) in 50 mL of 70% ethanol with stirring at 200 rpm for 2 h at 50 °C. Subsequently, the extract was centrifuged at 3,000 rpm for 15 min at room temperature and the supernatant stored at -20 °C for the different analyses. In another study, Saikia et al. (2015) prepared an extract with acidified ethanol (1% 1N hydrochloric acid, pH 3.0) at a ratio of 1:10 (w/v) with different percentages of solvent, and different temperatures (Table 3). The extract was stirred for 3 h and the extracting solution was then centrifuged at 3,000 rpm for 15 min. Finally, Güevara et al. (2019) carried out a hydro-alcoholic extraction, but did not mention the methodology.
### 4.3 Extraction using methanol and mixed polar solvents

Mahattanatetwee et al. (2006) used a 1:4 (w/v) ratio with absolute methanol, mixing in a blender for 1 min. The extract was then filtered and the residue re-extracted and filtered. Finally, the extracts were combined and concentrated in a rotavaporator at 40 °C. Bhat et al. (2011) used a ratio of 1:1 (w/v) for extraction, stirring at 1,100 rpm for 3 h and at 25 ± 1 °C followed by filtering and centrifugation at 3,000 g for 15 min. The supernatant was concentrated in a rotary evaporator at 50 °C. Subsequently, the extract was lyophilized and stored at 4 °C. Shofian et al. (2011) mentioned only mixing the lyophilized sample with absolute methanol; filtering the extractant solution and re-extracting twice more using fresh solvent. Finally, the three extracts were concentrated in a rotary evaporator. Annegowda et al. (2012) meanwhile performed the extraction with an ultrasound using a ratio of 1:10 (w/v) at different extraction times: 15, 30, 45, 60 min, at room temperature (25 ± 1 °C) and under low light conditions. After extraction, the sample residues were subjected to a second extraction following the same methodology, until obtaining a crystalline extract. The extracts were then filtered and concentrated in a rotary evaporator, and finally the concentrated extracts were lyophilized. Murillo et al. (2012) used an orbital shaker to mix the sample in methanol, at a 1:4 (w/v) ratio for 1 h at room temperature. Then, the extract was filtered using filter paper, and the residue obtained was re-extracted and filtered again. Zainudin et al. (2012) put the sample to macerate with methanol for 1 h at 40 ± 1 °C using a 1:3 (w/v) ratio. Subsequently, the extract was filtered after filter paper and the sample residue was re-extracted as mentioned above. The extracts were concentrated in a rotary evaporator and finally stored at -20 ± 1 °C. Batiston et al. (2013) used a 1:10 (w/v) sample-methanol ratio, stirring constantly for 4 h under low light conditions. Subsequently, the extract was filtered and the solvent evaporated in a rotary evaporator. Lim & Lee (2013) performed the extraction with 80% methanol (v/v) by means of an orbital shaker, at a ratio of 1:10 (w/v) for 2 h at room temperature and at 150 rpm. The extract was filtered through filter paper and then concentrated in a rotary evaporator at 45 °C for 1 h. The concentrated extract was re-mixed with 80% (v/v) methanol and stored at -80 °C. Zainudin et al. (2014) used a ratio of 1:10 (w/v) with absolute methanol for 1 h, performing this extraction twice consecutively. The extracts were filtered and concentrated in a rotary evaporator. The concentrated extracts were placed in airtight amber bottles, adding nitrogen and storing at -20 °C. Adiyaman et al. (2016) used a rotary agitator and a ratio of 1:3 (w/v) with 80% methanol for 24 h at room temperature, then filtered the extract and centrifuged it at 8,000 rpm for 15 min. The supernatant was used for the different tests. Rahman et al. (2016) mixed 10 g of plant sample with 70% methanol, stirring for 1 h. The extractant solution was filtered through filter paper and re-extracted twice more using fresh solvent. The extracts obtained were concentrated in a rotary evaporator at 40 °C. Recuenco & Lacasmama (2016) mixed the vegetable sample with 80% methanol in a blender using a ratio of 1:25 (w/v) for 5 min. The extract was then filtered and finally stored at 4 °C in dark bottles. Verma et al. (2018) performed the extraction using a soxhlet apparatus. The vegetable sample was first defatted with 250 mL of 98% petroleum ether for 6 h, followed by 250 mL of chloroform for 9 h and 250 mL of methanol. Subsequently, the methanolic fraction was filtered through filter paper and concentrated in a rotary evaporator at 40 °C, and finally the extract was stored at 4 °C.

### 4.4 Extraction using other solvents

Some authors carried out the extraction of phenolic compounds and A. carambola L. using other solvents. Luximon-Ramma et al. (2003) mixed 100 g of sample in 70% acetone (v/v) using a blender and leave it to macerate for 24 h at 4 °C. Acetone was removed from the extract by vacuum filtering at 37 °C. The aqueous extract was washed with dichloromethane (3 x 150 mL) to remove fat-soluble substances. Subsequently, the extract was concentrated at 37 °C and divided into two aliquots. The first aliquot was lyophilized and this was dissolved in methanol using a ratio of 1:5 (v/v) and the result was used to determine phenolic compounds. The second aliquot was used to determine antioxidant capacity. Shui & Leong (2006) obtained a juice by liquefying the sample, then lyophilized and pulverized it. They used the powder to carry out extractions with ethanol and acetone at different concentrations, temperatures and extraction times (Table 3). However, the extract analyzed in his study was an extract with acetone.

Pang et al. (2016) used the fruit from various cultivars (Table 3). They performed an extract to determine free phenolic compounds. They mixed 25 g of fresh sample in 80 mL of 80% acetone for 5 min, then centrifuged the extract at 2,500 g for 10 min. This process was then repeated. Subsequently, the supernatants were combined and filtered through filter paper, and concentrated at 45 °C. The concentrated extract was mixed with 25 mL of distilled water and stored at -40 °C. The residues obtained in this extraction were used to extract bound phenolic compounds. Those residues were digested by stirring for 90 min at room temperature. These authors used 50 mL of sodium hydroxide and a stream of nitrogen. Subsequently, the sample was acidified to a pH of 2 with hydrochloric acid and extracted 5 times with ethyl acetate; these were evaporated at 45 °C. The concentrated extract was mixed with 5 mL of distilled water and stored at -40 °C. Esteban Muñoz et al. (2018) used 20 mL of diethyl ether to extract the compounds; the extract was stored at -20 °C for 24 h. It was then centrifuged at 9,000 rpm for 10 min. The supernatant was separated in a funnel and three extractions were generated with 20 mL of diethyl ether, anhydrous sodium sulfate was added to the extract. Subsequently, it was filtered and concentrated in a rotary evaporator at 30 °C. The concentrated extracts were mixed with 1:1 methanol-water (v/v) followed by filtration through a 0.20 µm membrane to introduce it to the chromatographic system.

### 4.5 Extraction without the use of solvents

Thomas et al. (2016) used only the fresh juice of the A. carambola L. fruit to determine TPC content. Saikia et al. (2016) used different methods to extract the compounds of interest from the fruit juice. They extracted 100 mL of the fruit juice in a water bath at 75 °C for 3 h. Using a microwave, they heated 25 mL of fruit juice to 600w and 900W (75 °C and 80 °C) for 30 seconds. They also used ultrasound (100-watt power and
30 ± 3 KHz frequency) in which they placed 100 mL of the fruit juice for 30 min at 50 ± 1 °C. Finally, all batches were stored at -20 °C.

Most of the extraction methods are conventional methods, except those used by Leong & Shui (2002), Annegowda et al. (2012), and Saikia et al. (2016) who use unconventional methods (sonicator, microwave) and obtained more reliable results those from conventional methods. The advantage of unconventional methods is that less time and solvent are needed to perform the extraction, and they result in a greater quantity of bioactive compounds (Rocchetti et al., 2019). On the other hand, in each extraction methodology there are variables—time, temperature, the concentration of solvents and the solid/solvent ratio—that differ from one study to the next. All of these are variables may intervene in obtaining phenolic compounds and make it difficult to draw direct comparisons between the results (Soto-Garcia & Rosales-Castro, 2016).

### 5 Phenolic compounds present in *Averrhoa carambola* L.

Table 4 describes the phenolic compounds found in the fruit of *Averrhoa carambola* L. and reported by different authors, using the fresh fruit juice and solvents such as: water, ethanol, methanol and acetone.

Annegowda et al. (2012) determined the amount of total phenolic compounds (TPC) and total flavonoid content (TFC) in aqueous and methanolic extracts. The optimal time for aqueous extraction was reported at 15 min with 58.8 ± 0.60 mg gallic acid equivalents (GAE)/g in TPC and 27.6 ± 0.13 mg catechin equivalents (CE)/g in TFC. On the other hand, the optimal time for the methanolic extract was 30 min, with values of 142.0 ± 0.25 mg GAE/g of TPC and 79.7 ± 2.09 mg CE/g of TFC. After the optimal extraction time, the concentrations of phenolic compounds decreased for both extracts, probably due to oxidation (Tanase et al., 2019). Abdullah & Noriham (2014) for their part, performed aqueous extracts and compare the TPC and TFC of two types of *Averrhoa carambola* L. (tart-type and honey-type). The tart-type fruit contains a higher concentration of oxalic acid and its flavor is sour. The honey-type fruit contains a lower concentration of oxalic acid, is larger and its flavor is milder. The fruit were also classified by maturation stage (3 or 4). The authors reported a higher concentration in the tart-type stage 4 fruit, with 89.50 ± 0.76 mg GAE/g in TPC and 48.61 ± 0.25 mg QE/g in TFC. This study reported a higher amount of total phenolic compounds in aqueous extract with values of 2287.50 ± 0.31 mg GAE/100 g DW compared to *Averrhoa carambola* L. fruit. The results were similar to that obtained in common guava (*Psidium guajava*), with 138 ± 31 mg GAE/100 g FW, and higher than other tropical fruits such as the dragon fruit (*Hylocereus undatus*) and banana (*Musa sapientum*). In another study, Muñoz-Jáuregui et al. (2007) reported TPC concentrations of *Averrhoa carambola* L. and other fruits of Peru. They obtained a result of 75.97 mg GAE/100 g FW in the fruit of *Averrhoa carambola*. Similar results were obtained from other fruits, such as yacón (*Smallanthus sonchifolius*) with 67.64 mg GAE/100 g FW. However, the TPC concentration determined by these authors in the fruit of *Averrhoa carambola* L. was lower than that reported by Lim et al. (2007). Guevara et al. (2019) also analyzed the fruit of *Averrhoa carambola* L. and other fruits from coastal areas of Ecuador. The concentrations found in the fruit of *Averrhoa carambola* L. were 4280.83 ± 673.83 mg GAE/100 g FW and 48.52 ± 5.4 mg CE/g FW of TPC and TFC, respectively. The differences in the concentrations of phenolic compounds may be due to various factors, such as the agro-climatic conditions of each location, the maturity of the plant sample, post-harvest treatment, as well as extraction methodologies, the proportion of solvents and the solid-solvent ratio (Ben Ghorbal et al., 2018; Mahmood et al., 2012). Yan et al. (2013) analyzed a variety of the fruit, *Averrhoa carambola* L. along with *A. bilimbi*. finding a higher concentration of TPC in *A. carambola* L. with 1296.25 ± 14.74 mg GAE/100 g DW than in *A. bilimbi* L. with 629.17 ± 14.38 mg GAE/100 g DW and a lower concentration of TFC in *A. carambola* L., with 1296.25 ± 31 mg Rutin/100 g DW compared to *A. bilimbi* L. with values of 153.38 ± 8.02 mg Rutin/100 g DW. The TPC and TFC results obtained in *A. carambola* L. were superior to those reported by Khanam et al. (2015) and also higher than obtained by Ali et al. (2010) with 54.45 ± 0.43 mg GAE/100 mg of fruit of TPC. The study carried by Saikia et al. (2015) reported values from 2222.50 ± 0.34 to 2287.50 ± 0.31 mg GAE/100 g of TPC, obtaining the highest concentration at 40 °C and with 65% (v/v) of solvent.

The extraction of bioactive compounds depends on their solubility and the polarity of the solvent. There are other elements in the plant matrix as well that interfere in the extraction process. It has been observed, for example, that acidified solvents cause hydrolysis of these components of the plant matrix (Kopjar et al., 2014).

In methanolic extracts Shofian et al. (2011) analyzed fresh and lyophilized vegetable sample, reporting a higher amount of TPC in fresh matter, with values of 181.71 ± 8.83 mg GAE/100 g compared to 137.95 ± 4.31 mg GAE/100 g in the lyophilized extract. These results show a higher TPC compared to other fruits found in Malaysia such as mango (*mangifera indica L.*), papaya (*carica papaya L.*), muskmelon (*cucumis melo*), and watermelon *citrullus lanatus* (Thunb.). On the other hand, a study by Recuenco & Lacasamana (2016) also analyzed fresh and dried fruit, but obtained a higher concentration of both TPC and TFC

In ethanol extracts, Lim et al. (2007) analyzed the TPCs of the *A. carambola* L. fruit, among other tropical fruits from Malaysia, reporting 131 ± 54 mg GAE/100 g of fresh weight (FW) in the *A. carambola* L. fruit. The results were similar to that obtained in common guava (*Psidium guajava*), with 138 ± 31 mg GAE/100 g FW, and higher than other tropical fruits such as the dragon fruit (*Hylocereus undatus*) and banana (*Musa sapientum*). In another study, Muñoz-Jáuregui et al. (2007) reported TPC concentrations of *A. carambola* L. and other fruits of Peru. They obtained a result of 75.97 mg GAE/100 g FW in the fruit of *A. carambola*. Similar results were obtained from other fruits, such as yacón (*Smallanthus sonchifolius*) with 67.64 mg GAE/100 g FW. However, the TPC concentration determined by these authors in the fruit of *A. carambola* L. was lower than that reported by Lim et al. (2007). Guevara et al. (2019) also analyzed the fruit of *A. carambola* L. and other fruits from coastal areas of Ecuador. The concentrations found in the fruit of *A. carambola* L. were 4280.83 ± 673.83 mg GAE/100 g FW and 48.52 ± 5.4 mg CE/g FW of TPC and TFC, respectively. The differences in the concentrations of phenolic compounds may be due to various factors, such as the agro-climatic conditions of each location, the maturity of the plant sample, post-harvest treatment, as well as extraction methodologies, the proportion of solvents and the solid-solvent ratio (Ben Ghorbal et al., 2018; Mahmood et al., 2012). Yan et al. (2013) analyzed a variety of the fruit, *Averrhoa carambola* L. along with *A. bilimbi*. finding a higher concentration of TPC in *A. carambola* L. with 1296.25 ± 14.74 mg GAE/100 g DW than in *A. bilimbi* L. with 629.17 ± 14.38 mg GAE/100 g DW and a lower concentration of TFC in *A. carambola* L., with 1296.25 ± 31 mg Rutin/100 g DW compared to *A. bilimbi* L. with values of 153.38 ± 8.02 mg Rutin/100 g DW. The TPC and TFC results obtained in *A. carambola* L. were superior to those reported by Khanam et al. (2015) and also higher than obtained by Ali et al. (2010) with 54.45 ± 0.43 mg GAE/100 mg of fruit of TPC. The study carried by Saikia et al. (2015) reported values from 2222.50 ± 0.34 to 2287.50 ± 0.31 mg GAE/100 g of TPC, obtaining the highest concentration at 40 °C and with 65% (v/v) of solvent.

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| Solid-solvent ratio | % Solvent | Phenolic compounds reported | Reference |
|---------------------|-----------|----------------------------|-----------|
| **Extraction using water** |           |                            |           |
| 1:10 (w/v)          | 100%      | TPC: 60.5 ± 0.55 mg GAE/g, TFC: 28.8 ± 0.35 mg CE/g in 0 min | Annegowda et al. (2012) |
|                     |           | TPC: 58.8 ± 0.60 mg GAE/g, TFC: 27.6 ± 0.13 mg CE/g in 15 min |           |
|                     |           | TPC: 58.5 ± 1.15 mg GAE/g, TFC: 26.4 ± 0.35 mg CE/g in 30 min |           |
|                     |           | TPC: 55.3 ± 0.57 mg GAE/g, TFC: 26.8 ± 0.61 mg CE/g in 45 min |           |
|                     |           | TPC: 56.9 ± 0.71 mg GAE/g, TFC: 27.2 ± 0.48 mg CE/g in 60 min. |           |
| 1:30 (w/v)          | 100%      | TPC: 72.42 ± 2.98 mg GAE/g, stage 3 of honey-type maturity | Abdullah & Noriham (2014) |
|                     |           | TPC: 87.65 ± 2.57 mg GAE/g, stage 4 of honey-type maturity |           |
|                     |           | TPC: 79.38 ± 1.53 mg GAE/g, stage 3 of tart-type maturity |           |
|                     |           | TPC: 89.50 ± 1.15 mg GAE/g, stage 4 of tart-type maturity |           |
|                     |           | TPC: 79.38 ± 1.53 mg GAE/g, stage 3 of tart-type maturity |           |
|                     |           | TPC: 89.50 ± 1.15 mg GAE/g, stage 4 of tart-type maturity |           |
|                     |           | TPC: 41.63 ± 0.25 mg QE/g, stage 4 of honey-type maturity |           |
|                     |           | TPC: 34.26 ± 1.73 mg QE/g, stage 3 of tart-type maturity |           |
|                     |           | TPC: 48.61 ± 0.25 mg QE/g, stage 4 of type-tart maturity |           |
| 1:2 (w/v)           | NR        | TPC: 77.00 ± 2.89 mg GAE/g DW, TFC: 18.18 ± 1.00 mg QE/g DW | Khanam et al. (2015) |
| 2.5 (w/v)           | 60%       | TPC: 2.3 ± 0.7 g GAE/100 g FM and 1.0 ± 0.7 g GAE/100 g DM. | Chauhan & Kapfo (2016) |
| **Extraction using ethanol** |           |                            |           |
| NR                  | 50%       | TPC: 131 ± 54 mg GAE/100 g FW. | Lim et al. (2007) |
| NR                  | 60%       | TPC: 75.97 mg GAE/100 g FW. | Muñoz-Jáuregui et al. (2007) |
| 1:2 (w/v)           | 50%       | TPC: 54.45 ± 0.43 mg GAE/100 mg of fruit. | Ali et al. (2010) |
| 1:25 (w/v)          | 70%       | TPC: 1296.25 ± 14.74 mg GAE/100 g DW, TFC: 66.64 ± 13.41 mg Rutin/100 g DW. | Yan et al. (2013) |
| 1:10 (w/v)          | HCl IN    | TPC: 2222.50 ± 0.34 hasta 2287.50 ± 0.31 mg GAE/100 g. | Saikia et al. (2015) |
| 1:2 (w/v)           | NR        | TPC: 97.16 ± 4.29 mg GAE/g DW, TFC: 42.70 ± 1.47 mg QE/g DW | Khanam et al. (2015) |
| NR                  | NR        | TPC: 4280.83 ± 673.83 mg GAE/100 g FW, TFC: 48.52 ± 5.4 mg CE/g FW. | Guevara et al. (2019) |
| **Extraction using methanol** |           |                            |           |
| 1:4 (w/v)           | 100%      | TPC: 2207.7 ± 156.7 µg GAE/g puree FW. | Mahantatanaewee et al. (2006) |
| 1:10 (w/v)          | NR        | TPC: 6.05 ± 0.06 mg GAE/g, TFC: 2.32 ± 0.01 mg QE/100 g in 0 min | Bhat et al. (2011) |
|                     |           | TPC: 6.07 ± 0.02 mg GAE/g, TFC: 2.36 ± 0.03 mg QE/100 g in 30 min |           |
|                     |           | TPC: 6.09 ± 0.02 mg GAE/g, TFC: 2.47 ± 0.02 mg QE/100 g in 60 min |           |
| NR                  | NR        | TPC: 181.71 ± 8.83 mg GAE/100 g FM and 137.95 ± 4.31 mg GAE/100 g DM. | Shofian et al. (2011) |
| 1:10 (w/v)          | NR        | TPC: 120.8 ± 0.30 mg GAE/g, TFC: 63.8±2.24 mg CE/g in 0 min | Annegowda et al. (2012) |
| NR                  | NR        | TPC: 127.26 ± 1.48 mg GAE/100 g of sample. | Batiston et al. (2013) |
| 1:10 (w/v)          | 80%       | TPC: 16.18 ± 1.40 TAE/100 g FW, TFC: 7.06 ± 0.82 g QE/100 g FW in UF | Lim & Lee (2013) |
|                     |           | TPC: 39.89 ± 5.29 g TAE/100 g FW, TFC: 16.01 ± 2.07 CE/100 g FW in UF |           |
| 1:10 (w/v)          | 100%      | TPC: 234.89 ± 19.85 mg GAE/100 g FW, TFC: 205 ± 4.99 mg EE/100 g FW | Zainudin et al. (2014) |
| 1:3 (w/v)           | 80%       | TPC: 161.56 ± 9.24 mg GAE/100 g FW, TFC: 72.00 ± 2.69 mg QE/100 g FW | Adiyaman et al. (2016) |
| NR                  | 70%       | TPC: 31.76 ± 1.45 mg GAE/g FW | Rahman et al. (2016) |
| 1:20 (w/v)          | 80%       | TPC: 209 ± 15 mg GAE/100 g FM and 1490 ± 108 mg GAE/100 g DM, TFC: 101 ± 7 mg CE/100 g FM and 722 ± 53 mg CE/100 g DM | Recuenco & Lacasamana (2016) |
| **Extraction using acetone** |           |                            |           |
| NR                  | 70%       | TPC: 1429 ± 71 µg GAE/g FW, Flavonoids: 103 ± 11 µg QE/g FW | Luximon-Ramma et al. (2003) |
|                     | 50%       | TPC: 33.2 ± 3.6 mg GAE/g on a dry basis. | Shui & Leong (2006) |

CE: catechin equivalents; DM: dry matter; DW: dry weight; EE: epicatechin equivalent; FJ: fresh juice; FM: fresh weight; FW: fresh weight; GAE: gallic acid equivalent; MF: mature fruit; MP: Microwave-pasteurized juice; NR: no reported; PJ: pasteurized juice; QE: quercetin equivalent; TAE: Tannic acid equivalent; TFC: total flavonoid content; TPC: total phenol content; SFJ: sonicated fruit juice; UF: unripe fruit. Results presented as reported by the authors.
Phenolic profile of *Averrhoa carambola L.*

| Solid-solvent ratio | % Solvent | Phenolic compounds reported | Reference |
|---------------------|-----------|-----------------------------|-----------|
| 5:16 (w/v)          | 80%       | Free TPC: 162.5 ± 4.9 mg GAE/100 g FW in Honlong cultivars | Pang *et al.* (2016) |
|                     |           | Bound TPC: 12.0 ± 1.1 mg GAE/100 g FW in Honlong cultivars |           |
|                     |           | Free TPC: 225.1 ± 5.6 mg GAE/100 g FW In Hong cultivars |           |
|                     |           | Bound TPC: 16.9 ± 0.4 mg GAE/100 g FW In Hong cultivars |           |
|                     |           | Free TPC: 236.0 ± 5.0 mg GAE/100 g FW In Xiangmi cultivars |           |
|                     |           | Bound TPC: 19.7 ± 0.3 mg GAE/100 g FW In Xiangmi cultivars |           |
|                     |           | Free TPC: 286.8 ± 2.6 mg GAE/100 g FW In Taiguo cultivars |           |
|                     |           | Bound TPC: 6.4 ± 0.3 mg GAE/100 g FW In Taiguo cultivars |           |
|                     |           | Free TFC: 125.3 ± 2.3 mg CE/100 g FW In Hong cultivars |           |
|                     |           | Bound TFC: 4.9 ± 0.7 mg CE/100 g FW In Hong cultivars |           |
|                     |           | Free TPC: 186.8 ± 17.0 mg CE/100 g FW In Xiangmi cultivars |           |
|                     |           | Bound TPC: 7.8 ± 0.3 mg CE/100 g FW In Xiangmi cultivars |           |
|                     |           | Free TFC: 236.0 ± 5.0 mg CE/100 g FW In Taiguo cultivars |           |
|                     |           | Bound TFC: 1.1 ± 0.2 mg CE/100 g FW In Taiguo cultivars |           |

| Solvent free | TPC: 145.00 ± 0.35 mg GAE/100 mL and TFC: 23.25 ± 0.11 mg QE/100 mL in FJ | Saikia *et al.* (2016) |
|             | TPC: 158.00 ± 0.30 mg GAE/100 mL and TFC: 158.00 ± 0.30 mg QE/100 mL in PJ | Deena *et al.* (2017) |
|             | TPC: 650.12 ± 0.10 mg GAE/100 mL and TFC: 21.75 ± 0.31 mg QE/100 mL for MPJ (600W) | Ruvini *et al.* (2017) |
|             | TPC: 700.00 ± 0.15 mg GAE/100 mL and TFC: 19.25 ± 0.12 mg QE/100 mL for MPJ (900W) |           |
|             | TPC: 743.50 ± 0.14 mg GAE/100 mL and TFC: 35.75 ± 0.14 mg QE/100 mL for SFJ | Otero *et al.* (2020) |
|             | TPC: 131 ± 2.00 mg GAE/g | Thomas *et al.* (2016) |
|             | TPC: 60 ± 0.8 mg GAE/g | Deena *et al.* (2017) |
|             | TPC: 21.97 ± 0.98 and 24.92 ± 0.98 mg GAE/g in fresh sample of Arkin and Honey sweet cultivars, respectively | Ruvini *et al.* (2017) |
|             | TPC: 5.40 ± 0.36 and 4.13 ± 0.36 mg GAE/g in dehydrated sample of Arkin and Honey sweet cultivars, respectively |           |
|             | TPC: 6.93 ± 0.09 and 5.57 ± 0.36 mg GAE/g in oven-dried sample of Arkin and Honey sweet cultivars, respectively |           |
|             | TPC: 7.8 ± 0.3 mg CE/100 g FW In Honlong cultivars | Pang *et al.* (2016) |
|             | TFC: 100.7 ± 6.1 mg CE/100 g FW In Hong cultivars | Pang *et al.* (2016) |
|             | TFC: 125.3 ± 2.3 mg CE/100 g FW In Xiangmi cultivars | Pang *et al.* (2016) |
|             | TFC: 186.8 ± 17.0 mg CE/100 g FW In Taiguo cultivars | Pang *et al.* (2016) |
|             | TFC: 236.0 ± 5.0 mg CE/100 g FW In Taiguo cultivars | Pang *et al.* (2016) |
|             | TFC: 1.1 ± 0.2 mg CE/100 g FW In Taiguo cultivars | Pang *et al.* (2016) |

CE: catechin equivalents; DM: dry matter; DW: dry weight; EE: epicatechin equivalent; FJ: fresh juice; FM: fresh weight; GAE: gallic acid equivalent; MF: mature fruit; MPJ: Microwave-pasteurized juice; NR: no reported; PJ: pasteurized juice; QE: quercetin equivalent; TAE: Tannic acid equivalent; TFC: total flavonoid content; TPC: total phenol content; SFJ: sonicated fruit juice; UF: unripe fruit. Results presented as reported by the authors.

In the extract from dry matter, with values of 1490 ± 108 mg GAE/100 g and 722 ± 53 mg EC/100 g respectively; while the values reported from fresh matter extract were 209 ± 15 mg GAE/100 g of TPC and 101 ± 7 mg EC/100 g of TFC. Phenolic compounds were frequently in different states of union, which explains why the drying process can cause variations in TPC concentration (Chauhan & Kapfo, 2013). Furthermore, the concentrations of phenolic compounds in *A. carambola L.* were higher than other fruits such as *Pithecellobium dulce*, *Psidium guajava*, and *Litchi chinensis*, analyzed in this study (carried out in the Philippines). Lim & Lee (2013) analyzed TPC and TFC in mature and immature *A. carambola L.* samples, reporting TPC values of 16.18 ± 1.40 g tannic acid equivalent (TAE)/100 g FW and TFC values of 7.06 ± 0.82 g Catechin equivalent (CAE)/100 g FW in immature sample. Likewise, they reported TPC values of 39.89 ± 5.29 g TAE/100 g FW and TFC values of 16.01 ± 2.07 g CAE/100 g FW in mature sample. Similar results were reported by Abdullah & Noriham (2014) who obtained higher values of phenolic compounds in *A. carambola L.* at the highest stage of fruit maturity. As a fruit matures, it undergoes physical and biochemical changes that may explain the higher concentration of phenolic compounds and antioxidant capacity found in most fruits in a certain state of maturity (Nobossé *et al.*, 2018). A study by Zainudin *et al.* (2014) reported TPC values of 234.89 ± 19.85 mg GAE/100 g FW and TFC values of 205 ± 4.99 mg catechin equivalent (EE)/100 g FW. These were higher than the results obtained by Adiyaman *et al.* (2016) who recorded TPC values of 161.56 ± 9.24 mg GAE/100 g FW and TFC values of 72.00 ± 2.69 mg QE/100 g FW. Studies by Zainudin *et al.* (2012) and Batiston *et al.* (2013) reported similar concentrations of...
TPC with values of 117.72 ± 13.75 mg GAE/100 g FW; and 127.26 ± 1.48 mg GAE/100 g of sample, respectively. These results were comparable to the TPC values reported in the guava (Psidium guajava L.) with 127.54 ± 2.01 mg GAE/100 g of sample reported in a study by Batiston et al. (2013). Zainudin et al. (2012) did not report a significant difference in the TPC values of A. carambola L. samples that have been washed, cut and stored in the dark, compared to samples stored under fluorescent light for 12 days. On the other hand, before performing the methanolic extraction, Bhat et al. (2011) exposed the vegetable sample (juice) to lamps with UV light of a radiation of 2,158 /m² (digital radiometer) for different periods of time (0, 30 and 60 min). The results showed a higher concentration of phenolic compounds at 60 min of UV light exposure, with TPC values of 0.69 ± 0.02 mg GAE/g and TPC of 2.47 ± 0.02 mg QE/100 g. This may be due to the activation of the enzyme phenylalanine ammonia-lyase by exposure to UV light, causing a decrease in the activity of the enzyme polyphenol oxidase (Zainudin et al., 2012). Murillo et al. (2012) reported a higher amount of TPC than did previous studies, with values of 259.20 mg GAE/100 g FW. But it is Rahman et al. (2016) who reported the highest concentration of TPC in the methanolic extract, with values of 31.76 ± 1.45 mg GAE/g FW, while Mahattanataweewee et al. (2006) reported lower concentrations of TPC in methanolic extracts with 2207.7 ± 156.7 µg GAE/g of FW puree.

Luximon-Ramma et al. (2003) used acetone as an extraction solvent for phenolic compounds, obtaining TPC values of 1429 ± 71 µg GAE/g FW, flavonoid values of 103 ± 11 µg QE/g FW and proanthocyanidins values of 896 ± 23 µg cyanidin chloride/g FW. TPC values lower than those reported by Mahattanataweewee et al. (2006) in methanolic extract. Shui & Leong (2006) reported TPC values of 32.2 ± 3.6 mg GAE/g on a dry basis using acetone as a solvent, concentrations slightly below that reported by Guevara et al. (2019) and higher than reported by Saikia et al. (2015) in an ethanolic extract.

Pang et al. (2016) studied various cultivars and found, generally speaking, a higher amount of free TPC and TFC than bound TPC and TFC. The Tai guo cultivar yielded the highest amount of free TPC and TFC, with values of 286.8 ± 2.6 mg GAE/100 g FW and 234.0 ± 9.0 mg CE/100 g FW respectively, following in descending order by the Xiangmi, Hong and Honglong cultivars. The highest amount of bound TPC and TFC was reported in the Xiangmi cultivar, with values of 19.7 ± 0.3 mg GAE/100 g FW and 7.8 ± 0.3 mg EC/100 g FW, respectively, following in descending order by the Hong, Honglong and Taigu cultivars. Phenolic compounds can be free or linked to other components of the plant cell wall. Aqueous and organic solvents were used to extract free phenolic compounds, while phenolic compounds linked to the plant matrix cannot be extracted using this type of solvent along, so alkaline or acidic hydrolysis methods were used (Su et al., 2014). Other studies have mentioned that alkaline hydrolysis can extract more of the bound TPC than acidic hydrolysis (Gao et al., 2017). However, it is essential to optimize factors such as solvents, extraction time and temperature, since these can result in a higher concentration of bound TPCs, or degradation of the compounds (Irakli et al., 2018). It is suggested that other methodologies for the hydrolysis of linked phenolic compounds be compared in future research.

Other authors used only the juice from A. carambola L. fruit, these included Saikia et al. (2016) who compared the amount of phenolic compounds in juice subjected to different extraction conditions. The authors reported the highest amount of TPC and TFC using an ultrasonicator with values of 743.50 ± 0.14 mg GAE/100 mL and 35.75 ± 0.14 mg QE/100 mL, respectively. Thomas et al. (2016) reported TPC values of 131 ± 2.00 mg GAE/100 g in the juice of A. carambola L., similar to the results reported by Saikia et al. (2016). Deena et al. (2017) meanwhile reported TPC values of 60 ± 0.8 mg GAE/g, higher than that reported by the other studies. These authors did not describe their extraction methodology, however, so it is difficult to know which factors may have influenced these values. Ruveni et al. (2017) analyzed the TPC values of two cultivars (Arkin and Honey sweet), using different drying methods: by dehydrator, in a drying oven and sun-drying. They reported the greatest amount of phenolic compounds in fruit samples treated in a drying oven, with values of 6.93 ± 0.09 and 5.57 ± 0.36 mg GAE/g in cultivars Arkin and Honey sweet, respectively. These were followed by the sample dried in a dehydrator and finally the sun-dried sample. In general, however, drying was found to reduce the amount of TPC in both cultivars compared to the values reported in the fresh sample: 21.97 ± 0.98 and 24.92 ± 0.98 mg GAE/g in the Arkin and Honey sweet cultivars, respectively. As mentioned above, drying methods regularly cause the inhibition of certain microorganisms and enzymes that can degrade the compounds of interest in the plant sample. Sun-drying is carried out at room temperature for prolonged times, which results in a slow loss of humidity and a gradual inactivation of polyphenol oxidase and peroxidase enzymes, causing the degradation of compounds of interest. On the other hand, the decrease in TPC values among the different drying methods may be due to the activity of these enzymes before the variables of temperature and moisture content reach the point necessary to inactivate them (Rababah et al., 2015; Teles et al., 2018). Without using solvents, Pothasak et al. (2020) found lower values of TPC and TFC than other studies, with values of 5.12 ± 0.24 µg GAE/100 g and 0.18 ± 0.008 µg QE/100 g, respectively.

6 Antioxidant capacity of A. carambola L.

In aqueous extracts, Shui & Leong (2004) reported antioxidant capacity using the 2,2’-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) technique with values of 227.8 mg L-ascorbic acid equivalent antioxidant capacity (VCEAC)/100 g and 293.8 mg VCEAC/100 g. (Table 5); while Annegowda et al. (2012) determined the antioxidant capacity in aqueous and methanolic extracts at different extraction times. Using the 1,1-diphenyl-2-picyrhydrazyl assay (DPPH) and ferric reducing antioxidant power assay (FRAP) techniques, they reported a small increase in antioxidant capacity by both techniques in methanolic extracts at 30 min. These authors reported 87.4 ± 0.41% inhibition by DPPH, and 2.4 ± 0.00 Mm ferric reduction to ferrous (FRF)/g by FRAP. In the aqueous extract they obtained values of 40.5 ± 0.96% inhibition by DPPH, and values of 1.14 ± 0.03 mM FRF/g by FRAP at 0 min, and 39.6 ± 0.35% inhibition by DPPH and 1.09 ± 0.01 mM FRF/g by FRAP, at 15 min. As the extraction time passes, a decrease in antioxidant capacity was observed. Abdullah & Norihm (2014) obtained a higher
### Phenolic Profile of *Averrhoa carambola* L.

#### Table 5. Antioxidant capacity reported in fruit *A. carambola* L.

| Solid-solvent ratio | % Solvent | Antioxidant capacity                                                                 | Reference |
|---------------------|-----------|--------------------------------------------------------------------------------------|-----------|
| Extraction using water                                      |           |                                                                                      |           |
| 1:10 (w/v)          | NR 50%    | DPPH: 40.5 ± 0.96% inhibition, FRAP: 1.14 ± 0.03 mM FRF/g in 0 min                   | Shui & Leong (2004) |
|                     |           | DPPH: 39.6 ± 0.35% inhibition, FRAP: 1.09 ± 0.01 mM FRF/g in 15 min                  | Annegowda et al. (2012) |
|                     |           | DPPH: 38.1 ± 0.75% inhibition, FRAP: 1.06 ± 0.00 mM FRF/g in 30 min                  |           |
|                     |           | DPPH: 38.0 ± 0.43% inhibition, FRAP: 1.04 ± 0.01 mM FRF/g in 45 min                  |           |
|                     |           | DPPH: 37.6 ± 0.82% inhibition, FRAP: 1.08 ± 0.01 mM FRF/g in 60 min                  |           |
| 1:30 (w/v)          | NR 50%    | DPPH: 74% inhibition (tart-type stage 4 maturity), FRAP: 5.1023 and 5.0759          | Abdullah & Noriham (2014) |
|                     |           | Mmol/TE (honey-type stage 4 maturity and type-tart stage 4 maturity, respectively), β-Carotene bleaching activity: 57.65 ± 4.42 AOX (%) (stage 3 honey-type maturity), 90.34 ± 1.65 AOX (%) (honey-type stage 4 maturity), 47.35 ± 1.97 AOX (%) (tart-type stage 3 maturity), 94.28 ± 1.42 AOX (%) (tart-type stage 4 maturity). |           |
| 2:5 (w/v)           | 60%       | DPPH: 100 ± 6.2 IC<sub>50</sub> µg/mL, TEAC: 0.37 ± 0.023 fresh fruit                | Chauhan & Kapfo (2016) |
|                     |           | DPPH: 150 ± 3.4 IC<sub>50</sub> µg/mL, TEAC: 1.05 ± 0.005 dried fruit               |           |
| Extraction using ethanol                                    |           |                                                                                      |           |
| 1:10 (w/v)          | 50%       | ABTS: 278 ± 22.3 mg VCEAC/100 g                                                    | Leong & Shui (2002) |
|                     | 50%       | DPPH: 3.8 ± 2.1 IC<sub>50</sub> mg/mL and 98 ± 55 mg VCEAC/100 g                   | Lim et al. (2007) |
|                     | 60%       | DPPH: 403.31 EC<sub>50</sub> mg/mL, TEAC: 0.80 µmol/g                              | Muñoz-Jáuregui et al. (2007) |
| 1:2 (w/v)           | 70%       | DPPH: 81.03 ± 1.97 mg TE/100 mg of fruit, FRAP: 78.770 ± 0.35 TE/100 mg of fruit     | Ali et al. (2010) |
| 2:25 (w/v)          | 70%       | DPPH: 1215.34 ± 101.98 µmol TE/g FW, FRAP: 3370.94 ± 308.02 µmol TE/g FW            | Guevara et al. (2019) |
| Extraction using methanol                                    |           |                                                                                      |           |
| 1:4 (w/v)           | 100%      | DPPH: 620.2 ± 40.9 µg GAE/g puree and ORAC: 12.9 ± 1.0 µg TE/g puree                 | Mahattanatawee et al. (2006) |
| 1:10 (w/v)          | NR        | DPPH: 85.74 ± 0.36% inhibition in 0 min                                             | Bhat et al. (2011) |
|                     |           | DPPH: 87.27 ± 0.28% inhibition in 30 min                                             |           |
|                     |           | DPPH: 88.08 ± 0.77% inhibition in 60 min                                             |           |
| 1:10 (w/v)          | NR        | DPPH: 87 and 95% inhibition in lyophilized and fresh fruit, respectively.            | Shofian et al. (2011) |
| 1:10 (w/v)          | NR 100%   | DPPH: 68.6 ± 1.80% inhibition, FRAP: 2.1 ± 0.01 Mm FRF/g in 0 min                   | Annegowda et al. (2012) |
|                     |           | DPPH: 77.2 ± 1.53% inhibition, FRAP: 2.3 ± 0.02 Mm FRF/g in 15 min                  |           |
|                     |           | DPPH: 87.4 ± 0.41% inhibition, FRAP: 2.4 ± 0.00 Mm FRF/g in 30 min                  |           |
|                     |           | DPPH: 83.3 ± 0.59% inhibition, FRAP: 2.3 ± 0.01 Mm FRF/g in 45 min                  |           |
|                     |           | DPPH: 79.1 ± 1.14% inhibition, FRAP: 2.2 ± 0.05 Mm FRF/g in 60 min                  |           |
| 1:4 (w/v)           | NR 100%   | DPPH: 500.00 mg TE/100 g FW                                                        | Murillo et al. (2012) |
| 1:3 (w/v)           | NR 100%   | DPPH: 1.31 ± 0.53 IC<sub>50</sub> mg/mL, FRAP: 19.78 ± 10.44 µmol TE/g FW           | Zainudin et al. (2012) |
| 1:10 (w/v)          | NR 100%   | DPPH: 73.48 ± 4.53 IC<sub>50</sub> mg/mL                                          | Batiston et al. (2013) |
| 1:10 (w/v)          | 80%       | DPPH: 22.82 ± 2.21% inhibition, FRAP: 0.16 ± 0.02 mM FeSO4/100 g FW in UF            | Lim & Lee (2013) |
|                     |           | DPPH: 38.85 ± 6.63% inhibition, FRAP: 0.52 ± 0.04 mM FeSO4/100 g FW in MF            |           |
| 1:10 (w/v)          | 100%      | DPPH: 0.625 IC<sub>50</sub> mg/mL                                                  | Zainudin et al. (2014) |
| 1:3 (w/v)           | 80%       | DPPH: 0.6 IC<sub>50</sub> mg/mL and 91.77 ± 8.68 mg VCEAC/100 g FW                   | Adiyaman et al. (2016) |
| NR 70%             |           | β-carotene bleaching: 63 ± 8 AOX (%)                                               | Rahman et al. (2016) |
| 01:25              | 80%       |                                             | Recuenco & Lascamana (2016) |

Extraction using acetone:

| Solid-solvent ratio | % Solvent | Antioxidant capacity                                                                 | Reference |
|---------------------|-----------|--------------------------------------------------------------------------------------|-----------|
| NR 50%              | 70%       | ABTS: 2949 ± 310 mg VCEAC/100 g and 5270 ± 46 mg TEAC/100 g on a dry basis, FRAP: 510.3 ± 68.1 µmol/g on a dry basis, DPPH: 3412 ± 290 mg VCEAC/100 g and 5152 ± 706 mg TEAC/100 g on a dry basis | Shui & Leong (2006) |

*ABTS*: 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); AOX: antioxidant activity; DPPH: 1,1-diphenyl-2-picrylhydrazyl assay; FeSO4: iron (II) sulfate; FJ: fresh juice; FRAP: ferric reducing antioxidant power assay; FRF: ferric reduction to ferrous; FW: fresh weight; GAE: Gallic acid equivalent; MF: mature fruit; MPJ: Microwave-pasteurized juice; NO: nitric oxide; NR: not reported; ORAC: oxygen radical absorbance capacity assay; PJ: pasteurized juice; PSC: Peroxyl radical scavenging capacity; SFJ: sonicated fruit juice; TE: trolox equivalent; TEAC: trolox equivalent antioxidant capacity; UF: unripe fruit; VCEAC: Vitamin C equivalent antioxidant capacity. Results presented as reported by the authors.
value of antioxidant capacity in the tart-type fruit in a mature state (stage 4) by means of the DPPH and FRAP technique. They reported 74% inhibition values and 5,1023 Mmol/trolox equivalent (TE), in DPPH and FRAP assays, respectively. Using the β-Carotene bleaching activity technique, they obtained a value of 94.28 ± 1.42% antioxidant activity (AOX). Chauhan & Kapfo (2016) analyzed the antioxidant capacity in fresh and dry matter using the DPPH and trolox equivalent antioxidant capacity (TEAC) techniques. They reported a higher antioxidant capacity in fresh matter by DPPH with 100 ± 6.2 IC_{50} µg/mL, and a lower antioxidant capacity using the TEAC technique with 0.37 ± 0.023. In contrast, they obtained a lower value of antioxidant capacity in dry matter by DPPH with 150 ± 3.4 IC_{50} µg/mL and a higher value by means of the TEAC technique with 1.05 ± 0.005. The authors attribute the antioxidant capacity to the compounds found in this study—protocatechuic acid trimer in dry matter and the synaptic acid in fresh and dry matter.

In ethanolic extracts, Leong & Shui (2002) reported 278 ± 22.3 mg VCEAC/100 g per ABTS, similar to what was reported in Psidium guajava with 270 ± 18.8 mg AEAC/100 g by ABTS in the same study. The result obtained from the fruit of A. carambola L. falls within the range reported by Shui & Leong (2004) in aqueous extract. Muñoz-Jáuregui et al. (2007) reported antioxidant capacity values of 403.31 EC_{50} mg/mL by DPPH, and 0.80 µmol/g by TEAC. In another study, Ruvini et al. (2017) obtained greater antioxidant capacity using a dehydrator for samples from both cultivars (Arkin and Honey sweet) reporting values of 179.27 ± 4.58 and 196.62 ± 4.80 IC_{50}, respectively, by DPPH. The lowest antioxidant capacity was reported in samples treated by the sun-drying process, with 395.26 ± 17.25 and 483.93 ± 9.43 IC_{50} in sun-dried samples of Arkin and Honey sweet cultivars, respectively.

### Table 5. Continued...

| Solid-solvent ratio | % Solvent | Antioxidant capacity | Reference |
|--------------------|-----------|----------------------|-----------|
| 5:16 (w/v)         | 80%       | ORAC: 49.84 ± 3.44 µmol TE FW in Taiguo cultivars, the highest values compared to other cultivars determined by extraction of free phenols. PSC: 457.6 ± 66.4 µmol VCEAC per 100 g FW in Taiguo cultivars, the highest values compared to other cultivars determined by extraction of free phenols. | Pang et al. (2016) |

**Extraction using diethyl ether**

| Solvent | ABTS: 1.02E+01 ± 3.465 Mmol TE/L of sample cultivated in Granada, Spain ABTS: 7.18E+00 ± 4.952 Mmol TE/L of sample cultivated in Malaga, Spain DPPH: 1.48E+01 ± 4.732 Mmol TE/L of sample cultivated in Granada, Spain DPPH: 1.56E+01 ± 4.273 Mmol TE/L of sample cultivated in Malaga, Spain FRAP: 7.78E+00 ± 1.854 Mmol TE/L of sample cultivated in Granada, Spain FRAP: 6.14E+00 ± 2.755 Mmol TE/L of sample cultivated in Malaga, Spain | Esteban Muñoz et al. (2018) |

**Solvent free**

| ABTS: 2.2′-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid); AOX: antioxidant activity; DPPH: 1,1-diphenyl-2-picrylhydrazyl assay; FeSO4: iron (II) sulfate; FJ: fresh juice; FRAP: ferric reducing antioxidant power assay; FRF: ferric reduction to ferrous; FW: fresh weight; GAE: Gallic acid equivalent; MF: mature fruit; MPJ: Microwave-pasteurized juice; NO: nitric oxide; NR: not reported; ORAC: oxygen radical absorbance capacity assay; P: pasteurized; PJ: pasteurized juice; PSC: Peroxyl radical scavenging capacity; SFJ: sonicated fruit juice; TE: trolox equivalent; TEAC: trolox equivalent antioxidant capacity; UF: unripe fruit; VCEAC: Vitamin C equivalent antioxidant capacity. Results presented as reported by the authors. |

| DPPH: 97.11% inhibition, FRAP: 1221.76% inhibition in FJ DPPH: 97.02% inhibition, FRAP: 1395.01% inhibition in PJ DPPH: 85.58% inhibition, FRAP: 1659.86% inhibition in MPJ (600W) DPPH: 86.37% inhibition, FRAP: 1829.58% inhibition in MPJ (900W) DPPH: 88.77% inhibition, FRAP: 680.56% inhibition by SFJ DPPH: 164.87 ± 8.37 and 178.89 ± 5.43 IC_{50} in fresh samples of Arkin and Honey sweet cultivars, respectively DPPH: 179.27 ± 4.58 and 196.62 ± 4.80 IC_{50} in dehydrated samples of Arkin and Honey sweet cultivars, respectively DPPH: 210.77 ± 5.87 and 312.27 ± 3.88 IC_{50} in oven-dried drying samples of Arkin and Honey sweet cultivars, respectively DPPH: 395.26 ± 17.25 and 483.93 ± 9.43 IC_{50} in sun-dried samples of Arkin and Honey sweet cultivars, respectively ABTS: 18.1 ± 0.51 Mmol TE/g DM, FRAP: 4.61 ± 0.70 Mmol TE/g DM ABTS: 722.71 ± 12.25 µg GAE/g extract, NO: 190 µmol/L extract and 27.48 ± 1.8 IC_{50} µg extract | Saikia et al. (2016) Ruvini et al. (2017) Otero et al. (2020) Pothasak et al. (2020) |
aqueous extract. In the studio by Yan et al. (2013) the antioxidant activity of A. carambola L. was found to be higher than the variety A. bilimbi L. with 6.93 ± 0.25 IC₅₀ mg/mL by DPPH and 28.41 ± 5.31% by the β-Carotene bleaching assay. Ali et al. (2010) reported antioxidant capacity values in A. carambola L. of 81.03 ± 1.97 mg TE/100 mg of fruit by DPPH and 78.77 ± 0.35 TE/100 mg of fruit by FRAP, lower values than those obtained from Psidium guajava, with 176.06 ± 1.92 TE/100 mg of fruit by DPPH, and 139.29 ± 0.54 TE/100 mg of fruit by FRAP, in the same study. Guevara et al. (2019) reported antioxidant capacity values in A. carambola L. of 1215.34 ± 101.98 µmol TE/g FW by DPPH and values of 3370.94 ± 308.02 µmol TE/g FW by FRAP.

In methanolic extracts, Bhat et al. (2011) reported a small increase in antioxidant capacity with inhibition percentage values from 85.74 ± 0.36% to 88.08 ± 0.77% inhibition by means of DPPH, after exposing the sample to UV light from 0 to 60 min, respectively. Similar results were reported by Shofian et al. (2011) by the DPPH technique with results of 87% and 95% inhibition in lyophilized and fresh samples, respectively. This difference in results was probably due to a series of changes in the chemical structures when cold-drying, causing oxidation of certain compounds (Marques et al., 2006). Rahman et al. (2016) reported 75.00% inhibition by DPPH, a slightly different from what was reported by Shofian et al. (2011), but consistent with the findings of Annegowda et al. (Annegowda et al., 2012) in methanolic extract. Lim & Lee (2013) analyzed antioxidant capacity in immature and mature samples, and find it greater in mature samples, with values of 38.85 ± 6.63% inhibition by DPPH and 0.52 ± 0.04 mM FeSO₄/100 g FW by FRAP. Batiston et al. (2013) reported antioxidant capacity values in A. carambola L. of 73.48 ± 4.53 IC₅₀ mg/mL per DPPH. These values were higher than those obtained in Psidium guajava L. with values of 118.22 ± 3.89 IC₅₀ mg/mL per DPPH, reported in the same study. However, Zainudin et al. (2012) obtained higher antioxidant capacity analyzed by DPPH, with values of 1.31 ± 0.53 IC₅₀ mg/mL and 19.78 ± 10.44 µmol TE/g FW by FRAP. These results were similar to those reported by Yan et al. (2013) but from ethanolic extract. Adiyaman et al. (2016) reported high antioxidant capacity by DPPH in A. carambola L. with values of 0.6 IC₅₀ mg/mL, a result that agrees with that reported by Zainudin et al. (2014) with 0.625 IC₅₀ mg/mL. Murillo et al. (2012) studied the antioxidant capacity of some fruits of Panama, including A. carambola L., determining values of 500.00 mg TE/100 g FW by DPPH. In this study, however, the results were lower than those reported in Psidium guajava L., values of 780.00 TE/100 g FW in the same study. Mahattanatawee et al. (2006) reported antioxidant capacity values by DPPH of 620.2 ± 40.9 µg GAE/g of puree and by oxygen radical absorbance capacity assay (ORAC) values of 12.9 ± 1.0 µg TE/g of puree in A. carambola L., reporting lower antioxidant capacity that in the study by Murillo et al. (2012). Recuenco & Lacasmana (2016) reported a value of 63 ± 8% AOX using the β-carotene bleaching technique, higher than was reported by Yan et al. (2013) in ethanolic extract.

Luximon-Ramma et al. (2003) studied various exotic fruits of Mauritius and find, in extracts of A. carambola L. prepared using acetone, antioxidant capacity values of 9 ± 0 µmol Fe (II)/g FW by FRAP and 11 ± 2 µmol TE/g by TEAC. This was higher than was found in fruits such as Psidium guajava L., orange (Passiflora edulis), and litchi (Litchi chinensis). The antioxidant capacity results in A. carambola L. reported by Shui & Leong (2006) range from 3490 ± 310 to 5270 ± 46 mg TEAC/100 g on a dry basis by ABTS; 3412 ± 290 mg AEAC/100 g and 5152 ± 706 mg TEAC/100 g on a dry basis by DPPH, and by means of FRAP, the authors reported values of 510.3 ± 68.1 µmol/g on a dry basis. Pang et al. (2016) reported the antioxidant capacity of the extract of free phenols with values of 49.84 ± 3.44 µmol TE g FW by the ORAC method in the cultivar of Taiguo, 1.4 times greater than the Xiangmi cultivar, and 1.51 and 2.1 times greater than the Hong and Honglong cultivars, respectively. The Taiguo cultivar yielded the highest amount, 457.6 ± 66.4 µmol VCEAC per 100 g FW, using the peroxy radical scavenging capacity (PSC) technique, 42.02% higher than for the Xiangmi cultivar, and 42.36% and 61.21% higher than the Hong and Honglong cultivars, respectively. In these results; as previously mentioned, different factors influenced the maturity of the fruit and the environmental conditions of each cultivar (Ben Ghorbal et al., 2018). Esteban Muñoz et al. (2018) used diethyl ether to make extracts and compare the antioxidant capacity of the A. carambola L. fruit cultivated in Granada, Spain and in Malaga, Spain. Through the ABTS method they reported values of 10.2 ± 3.465 Mmol TE/L in the Granada sample and 7.18 ± 4,952 Mmol TE/L in the Malaga sample. By means of DPPH they obtained values of 14.8 ± 4.732 Mmol TE/L from the Granada sample and 15.6 ± 4.273 Mmol TE/L from the Malaga sample, and finally by the FRAP method they obtained values of 7.78 ± 1.854 Mmol TE/L in the Granada sample and 6.14 ± 2,755 Mmol TE/L in the Malaga sample.

Saikia et al. (2016) reported the antioxidant capacity in fresh sample by different extraction methods without the use of solvent. Values ranged from 85.58% to 97.11% inhibition by means of the DPPH technique, not a significant difference. Using the FRAP technique, inhibition values from 680.56% to 1829.58% were reported. In general, the microwave extraction method resulted in higher antioxidant capacity, probably because the phenolic compounds found in the vegetable matrix of the juice of A. carambola L. are released when heated for a short period of time (Lović et al., 2017). Otero et al. (2020) obtained antioxidant capacity values of 18.1 ± 0.51 Mmol TE/g DM by ABTS and values of 4.61 ± 0.70 Mmol TE/g DM by FRAP, results than what was reported by Esteban Muñoz et al. (2018). Pothasak et al. (2020) for their part, reported antioxidant capacity values of 722.71 ± 12.25 µg GAE/g extract by ABTS, and values of 190 µmol/L using the nitric oxide (NO) technique.

7 Identification of phenolic compounds in fruit A. carambola L.

A study by Shui & Leong (2004) on the identification of phenolic compounds from the fruit of A. carambola L. in aqueous extracts, reported the presence of (-) epicatechin and proanthocyanidins by means of HPLC-DAD-ESI-MS (Table 6). Chauhan & Kapfo (2016) reported only the presence of protocatechuic acid trimmer and sinapic acid tetramer in aqueous extract using HPLC-ESI-MS and FT-IR. Khanam et al. (2015) performed an aqueous extraction of the fruit of A. carambola L. and analyzed the phenolic compounds using HPLC. They reported different percentages of
Table 6. Identification of phenolic compounds in the fruit of fruit *A. carambola* L.

| Solid to solvent ration | % Solvent | Technique used | Phenolic compounds identified                                      | Reference                |
|-------------------------|-----------|----------------|--------------------------------------------------------------------|--------------------------|
| Extraction using water  |           |                |                                                                    |                          |
| NR                      | 50%       | HPLC-DAD-ESI-MS| (-)Epicatechin and proanthocyanidins                                | Shui & Leong (2004)      |
| 1:2 (w/v)               | NR        | HPLC           | Gallic acid: 1.96 ± 0.59%                                           | Khanam et al. (2015)     |
|                         |           |                | 4-Hydroxycinnamic acid: 0.50 ± 0.56%                                |                          |
|                         |           |                | 4-Hydroxy-3-methoxycinnamic: 1.11 ± 0.31%                            |                          |
|                         |           |                | Vanillic acid: 2.41 ± 0.52%                                         |                          |
|                         |           |                | Apigenin: 0.36 ± 0.81%                                              |                          |
|                         |           |                | Kaempferol: 3.32 ± 0.67%                                            |                          |
|                         |           |                | Luteolin: 1.39 ± 0.80%                                              |                          |
|                         |           |                | Naringenin: 1.38 ± 0.23%                                            |                          |
|                         |           |                | Quercetin: 65.66 ± 0.12%                                            |                          |
| 2:5 (w/v)               | 60%       | HPLC-ESI-MS and FT-IR | Protocatechuic acid trimer and sinapic acid tetramer | Chauhan & Kapfo (2016) |
| Extraction using acetone|           |                |                                                                    |                          |
| NR                      | 50%       | HPLC/MS        | (-)Epicatechin and proanthocyanidins                                | Shui & Leong (2006)      |
| 5:16 (w/v)              | 80%       | HPLC           | Epicatechin: 3.81 ± 0.41 mg per 100 g FW in Honlong cultivars        | Pang et al. (2016)       |
|                         |           |                | 9.18 ± 0.19 mg per 100 g FW In Hong cultivars                       |                          |
|                         |           |                | 16.60 ± 0.19 mg per 100 g FW In Xiangmi cultivars                   |                          |
|                         |           |                | 10.65 ± 0.35 mg per 100 g FW In Taiguo cultivars                    |                          |
|                         |           |                | Procyanidin B2;                                                    |                          |
|                         |           |                | 7.34 ± 0.47 mg per 100 g FW in Honlong cultivars                    |                          |
|                         |           |                | 13.85 ± 3.10 mg per 100 g FW In Hong cultivars                      |                          |
|                         |           |                | 17.84 ± 0.54 mg per 100 g FW In Xiangmi cultivars                   |                          |
|                         |           |                | 19.27 ± 0.95 mg per 100 g FW In Taiguo cultivars                    |                          |
|                         |           |                | Isoquercetin: 1.12 ± 0.08 mg per 100 g FW in Honlong cultivars      |                          |
|                         |           |                | 1.00 ± 0.40 mg per 100 g FW In Hong cultivars                       |                          |
|                         |           |                | 1.43 ± 0.02 mg per 100 g FW In Xiangmi cultivars                    |                          |
|                         |           |                | 1.28 ± 0.05 mg per 100 g FW In Taiguo cultivars                     |                          |
|                         |           |                | Gallic acid: 1.00 ± 0.05 mg per 100 g FW in Honlong cultivars       |                          |
|                         |           |                | 0.55 ± 0.07 mg per 100 g FW In Hong cultivars                       |                          |
|                         |           |                | 1.30 ± 0.04 mg per 100 g FW In Xiangmi cultivars                    |                          |
|                         |           |                | 0.32 ± 0.01 mg per 100 g FW In Taiguo cultivars                     |                          |
|                         |           |                | Syringic acid: 0.20 ± 0.01 mg per 100 g FW in Honlong cultivars     |                          |
|                         |           |                | 0.27 ± 0.13 mg per 100 g FW In Hong cultivars                       |                          |
|                         |           |                | 0.21 ± 0.02 mg per 100 g FW In Xiangmi cultivars                    |                          |
|                         |           |                | 0.62 ± 0.02 mg per 100 g FW In Taiguo cultivars                     |                          |
|                         |           |                | p-coumaric acid: 2.03 ± 0.48 mg per 100 g FW in Honlong cultivars   |                          |
|                         |           |                | 4.19 ± 0.16 mg per 100 g FW In Hong cultivars                       |                          |
|                         |           |                | 4.89 ± 0.32 mg per 100 g FW In Xiangmi cultivars                    |                          |
|                         |           |                | 4.04 ± 0.82 mg per 100 g FW In Taiguo cultivars                     |                          |
| Extraction using ethanol|           |                |                                                                    | Muñoz-Jáuregui et al. (2007) |
| NR                      | 60%       | HPLC           | Chlorogenic Acid: 1.68 mg/kg FW                                      |                          |
|                         |           |                | Caffeic acid: 0.33 mg/kg FW                                         |                          |
|                         |           |                | Routine: 0.24 mg/kg FW                                              |                          |
|                         |           |                | Ferulic acid: 3.11 mg/kg FW                                         |                          |
|                         |           |                | Morine: 0.01 mg/kg FW                                               |                          |
|                         |           |                | Quercithin: 0.004 mg/kg FW                                          |                          |
|                         |           |                | Kaempferol: 0.04 mg/kg FW                                           |                          |

FW: fresh weight; NR: Not reported; FJ: fresh juice; MPJ: Microwave-pasteurized juice; PJ: pasteurized juice; SFJ: sonicated fruit juice. Results presented as reported by the authors.
Table 6. Continued...

| Solid to solvent ration | % Solvent | Technique used | Phenolic compounds identified | Reference |
|-------------------------|-----------|----------------|-------------------------------|-----------|
| 1:2 (w/v)               | NR        | HPLC           | Chlorogenic acid: 1.94 ± 0.25% | Khanam et al. (2015) |
|                         |           |                | Gallic acid: 6.47 ± 0.37%      |           |
|                         |           |                | 4-Hydroxy-cinnamic acid: 3.59 ± 0.43% |           |
|                         |           |                | 4-Hydroxy-3-methoxycinnamic: 1.87 ± 0.54% |           |
|                         |           |                | Vanillic acid: 4.54 ± 0.99%    |           |
|                         |           |                | Kaempferol: 4.25 ± 0.41%       |           |
|                         |           |                | Luteolin: 11.40 ± 0.39%        |           |
|                         |           |                | Myricetin: 1.77 ± 0.43%        |           |
|                         |           |                | Naringenin: 3.43 ± 0.82%       |           |
|                         |           |                | Quercetin: 0.37 ± 0.11%        |           |
| 1:10 (w/v)              | HCl 1N    | RP-HPLC        | Gallic acid: 41.90 ± 0.05 extract mg/100 g in pomace | Saikia et al. (2015) |
|                         |           |                | Caffeic acid: 38.09 ± 0.02 extract mg/100 g in pomace |           |
|                         |           |                | Chlorogenic acid: 22.01 ± 0.05 extract mg/100 g in pomace |           |
|                         |           |                | Syringic acid: 13.10 ± 0.09 extract mg/100 g in pomace |           |
|                         |           |                | Ferulic acid: 21.30 ± 0.11 extract mg/100 g in pomace |           |
|                         |           |                | Coumaric acid: 21.45 ± 0.03 extract mg/100 g in pomace |           |
|                         |           |                | Rutin: 2.41 ± 0.02 extract mg/100 g in pomace |           |
|                         |           |                | Quercetin: 3.67 ± 0.04 extract mg/100 g in pomace |           |
|                         |           |                | Gallic acid: 4.89 ± 0.04 extract mg/100 g in juice |           |
|                         |           |                | Caffeic acid: NR |           |
|                         |           |                | Chlorogenic acid: 2.17 ± 0.08 extract mg/100 g in juice |           |
|                         |           |                | Syringic acid: 3.51 ± 0.04 extract mg/100 g in juice |           |
|                         |           |                | Ferulic acid: 4.21 ± 0.03 extract mg/100 g in juice |           |
|                         |           |                | Coumaric acid: NR |           |
|                         |           |                | Rutin: NR |           |
|                         |           |                | Quercetin: NR |           |
| NR                     | NR        | UPLC-ESI-MS/MS  | Caffeic acid: 1.37E+02 ± 0.011 µg/100 g of fresh fruit | Esteban Muñoz et al. (2018) |
|                         |           |                | Ferulic acid: 2.84E+02 ± 0.022 µg/100 g of fresh fruit |           |
|                         |           |                | p-cumaric: 4.00E+02 ± 0.020 µg/100 g of fresh fruit |           |
|                         |           |                | Gallic acid: 4.75E+03 ± 0.230 µg/100 g of fresh fruit |           |
|                         |           |                | Vanillic acid: 1.68E+02 ± 0.002 µg/100 g of fresh fruit |           |
|                         |           |                | Ellagic acid: 7.43E+02 ± 0.067 µg/100 g of fresh fruit |           |
|                         |           |                | p-hydroxybenzoic acid: 1.59E+0.3 ± 0.090 µg/100 g of fresh fruit |           |
|                         |           |                | Protocatechuic acid: 1.21E+02 ± 0.010 µg/100 g of fresh fruit |           |
|                         |           |                | 3,5-Dimethoxybenzoic acid: 2.50E+02 ± 0.034 µg/100 g of fresh fruit |           |
|                         |           |                | Quercetin: 1.52E+01 ± 0.001 µg/100 g of fresh fruit |           |
|                         |           |                | Naringenin: 3.75E+00 ± 0.002 µg/100 g of fresh fruit |           |
| 1:4 (w/v)               | 100%      | HPLC-PDA-MS    | Catechin, proanthocyanidin dimer and trimer conjugates | Mahattanatawee et al. (2006) |
| 1:3 (w/v)               | 80%       | HPLC           | Gallic acid: 3.78 ± 0.31 mg/100 g FW | Adiyaman et al. (2016) |
|                         |           |                | Ferulic acid: 16.32 ± 1.56 mg/100 g FW |           |
|                         |           |                | Caffeic acid: 5.01 ± 0.42 mg/100 g FW |           |
|                         |           |                | Epi-catechin: 17.42 ± 1.75 mg/100 g FW |           |
|                         |           |                | Catechin: 1.33 ± 0.04 mg/100 g FW |           |
|                         |           |                | Quercetin: 38.01 ± 2.16 mg/100 g FW |           |
| NR                     | NR        | HPTLC          | Gallic acid: 0.96% | Verma et al. (2018) |
|                         |           |                | Protocatechuic acid: 0.05% |           |
|                         |           |                | Quercetin: 0.40% |           |

FW: fresh weight; NR: Not reported; FJ: fresh juice; MPJ: Microwave-pasteurized juice; PJ: pasteurized juice; SFJ: sonicated fruit juice. Results presented as reported by the authors.
phenolic compounds: gallic acid 1.96 ± 0.59%; 4-hydroxycinnamic acid 0.50 ± 0.56%; 4-hydroxy-3-methoxycinnamic 1.11 ± 0.31%; vanillic acid: 2.41 ± 0.52%; apigenin 0.36 ± 0.81%; kaempferol 3.32 ± 0.67%; luteolin 1.39 ± 0.80%; naringenin 1.38 ± 0.23% and quercetin 65.66 ± 0.12%. Furthermore, these authors analyzed the phenolic profile in ethanolic extract and reported: chlorogenic acid 1.94 ± 0.25%; gallic acid 6.47 ± 0.37%; 4-hydroxycinnamic acid 3.59 ± 0.43%; 4-hydroxy-3-methoxycinnamic 1.87 ± 0.54%; vanillic acid 4.54 ± 0.99%; kaempferol 4.25 ± 0.41%; luteolina 11.40 ± 0.39%; myricetin 1.77 ± 0.43%; naringenin 3.43 ± 0.82% and quercetin 0.37 ± 0.11%. In general, they find greater amounts of phenolic compounds in the ethanolic extract than in the aqueous extract. On the other hand, Muñoz-Jáuregui et al. (2007) determined the HPLC concentration of different phenolic compounds in ethanolic extract and report: chlorogenic acid 1.68 mg/kg FW; caffeic acid 0.33 mg/kg FW; rutin 0.24 mg/kg FW; ferulic acid 3.11 mg/kg FW; morin 0.01 mg/kg FW; quercitin 0.004 mg/kg FW and kaemferol 0.04 mg/kg FW. Saikia et al. (2015) used RP-HPLC to determine the concentration of different phenolic compounds from ethanolic extracts of the pomace and fruit juice. The authors reported: gallic acid 41.90 ± 0.05 extract mg/100 g in pomace; catechin 48.08 ± 0.02 extract mg/100 g in pomace; caffeic acid 38.09 ± 0.02 extract mg/100 g in pomace; chlorogenic acid 22.01 ± 0.05 extract mg/100 g in pomace; syringic acid 13.10 ± 0.09 extract mg/100 g in pomace; ferulic acid 21.30 ± 0.11 extract mg/100 g in pomace; coumaric acid 21.45 ± 0.03 extract mg/100 g in pomace; rutin 2.41 ± 0.02 extract mg/100 g in pomace; quercetin 3.67 ± 0.04 extract mg/100 g in pomace; gallic acid 4.89 ± 0.04 extract mg/100 g in juice; catechin: 2.90 ± 0.01 extract mg/100 g in juice; chlorogenic acid 2.17 ± 0.08 extract mg/100 g in juice; syringic acid 3.51 ± 0.04 extract mg/100 g in juice and ferulic acid 4.21 ± 0.03 extract mg/100 g in juice. In the extract of the pomace of A. carambola L. other phenolic compounds different from those reported in the juice were identified. Furthermore, the concentrations of phenolic compounds were higher in this extract than in the juice of A. carambola L. Shui & Leong (2006) reported the presence of (-)-epicatechin, a compound that is one of the main components of proanthocyanidins in fruit, in an extract prepared with acetone and evaluated by HPLC/MS.

Pang et al. (2016) found the Xiangni cultivar to have the highest amount of epicatechin (16.60 ± 0.19 mg per 100 g FW), procyanidin B1 (7.84 ± 0.54 mg per 100 g FW), isoquercetin (1.43 ± 0.02 mg per 100 g FW), gallic acid (1.30 ± 0.04 mg per 100 g FW), and p-coumaric acid (4.89 ± 0.32 mg per 100 g FW). The Taiguó cultivar was found only be higher in syringic acid (0.62 ± 0.02 mg per 100 g FW), however, in this cultivar the authors also obtained high concentrations of epicatechin, procyanidin B1, isoquercetin, and p-coumaric acid compared to the other cultivars. No other compounds were reported such as caffeic acid, chlorogenic acid, ferulic acid, rutin, or quercetin as reported by Saikia et al. (2015) in ethanolic extract, but this probably due to the type of solvent and extraction process used.

Esteban Muñoz et al. (2018) analyzed the phenolic profile of A. carambola L. from an extract made with diethyl ether, using UPLC-ESI-MS/MS. They reported, in proportion to fresh fruit: caffeic acid

| Table 6. Continued... |
|-----------------------|
| Solid to solvent ratio | % Solvent | Technique used | Phenolic compounds identified | Reference |
|------------------------|-----------|----------------|-------------------------------|-----------|
| HPLC                   | Gallic acid: 4.89 ± 0.03 mg/L by means of FJ, 11.68 ± 0.05 mg/L by means of MPJ (900W), 8.94 ± 0.08 mg/L by means of SFJ. | Saikia et al. (2016) |
|                        | Catechin: 4.89 ± 0.04 extract mg/100 g in juice; catechin: 2.90 ± 0.01 extract mg/100 g in juice; chlorogenic acid 2.17 ± 0.08 extract mg/100 g in juice; syringic acid 3.51 ± 0.04 extract mg/100 g in juice and ferulic acid 4.21 ± 0.03 extract mg/100 g in juice. In the extract of the pomace of A. carambola L. other phenolic compounds different from those reported in the juice were identified. Furthermore, the concentrations of phenolic compounds were higher in this extract than in the juice of A. carambola L. Shui & Leong (2006) reported the presence of (-)-epicatechin, a compound that is one of the main components of proanthocyanidins in fruit, in an extract prepared with acetone and evaluated by HPLC/MS. | |
|                        | Caffeic acid: 2.22 ± 0.07 mg/L by means of FJ, 2.33 ± 0.05 mg/L by means of MPJ (600W), 1.96 ± 0.03 mg/L by means of SFJ. | |
|                        | Chlorogenic acid: 2.17 ± 0.06 mg/L by means of FJ, 4.23 ± 0.03 mg/L by means of PJ, 5.15 ± 0.02 mg/L by means of MPJ (900W), 3.63 ± 0.07 mg/L by means of SFJ. | |
|                        | Syringic acid: 3.51 ± 0.03 mg/L by means of FJ, 7.47 ± 0.12 mg/L by means of PJ, 8.48 ± 0.09 mg/L by means of MPJ (600W), 9.74 ± 0.07 mg/L by means of MPJ (900W), 6.18 ± 0.05 mg/L by means of SFJ. | |
|                        | Ferulic acid: 4.21 ± 0.06 mg/L by means of FJ, 14.41 ± 0.08 mg/L by means of PJ, 13.96 ± 0.06 mg/L by means of MPJ (600W), 18.83 ± 0.08 mg/L by means of MPJ (900W), 13.21 ± 0.09 mg/L by means of SFJ. | |
|                        | Coumaric acid: 2.81 ± 0.02 mg/L by means of MPJ (600W) and 2.36 ± 0.05 mg/L by means of SFJ. | |
|                        | Quercetin: 0.66 ± 0.02 mg/L by means of PJ and 0.65 ± 0.03 mg/L by means of SFJ. | |

FW: fresh weight; NR: Not reported; FJ: fresh juice; MPJ: Microwave-pasteurized juice; PJ: pasteurized juice; SFJ: sonicated fruit juice. Results presented as reported by the authors.
137 ± 0.011 µg/100 g; ferulic acid 284 ± 0.022 µg/100 g; p-cumaric acid 400 ± 0.200 µg/100 g; gallic acid 4,750 ± 0.230 µg/100 g; vanillic acid 168 ± 0.002 µg/100 g; ellagic acid 743 ± 0.067 µg/100 g; p-hydroxybenzoic acid 1,590 ± 0.090 µg/100 g; protocatechuic acid 121 ± 0.010 µg/100 g; 3,5-dimethoxybenzoic acid 250 ± 0.034 µg/100 g; quercetin 15.2 ± 0.001 µg/100 g; and naringenin 3.75 ± 0.002 µg/100 g. Mahattanawatee et al. (2006) used HPLC-PDA-MS to report the presence of catechin, proanthocyanidin dimer and trimer conjugates in a methanolic extract. Adiyaman et al. (2016) determined the concentration and identification of the following compounds using HPLC in a methanolic extract: gallic acid 3.78 ± 0.31 mg/100 g FW; ferulic acid 16.32 ± 1.56 mg/100 g FW; caffeic acid 5.01 ± 0.42 mg/100 g FW; epi-catechin 17.42 ± 1.75 mg/100 g FW; catechin 1.33 ± 0.04 mg/100 g FW; quercetin 38.01 ± 2.16 mg/100 g FW. Verma et al. (2018) analyzed a methanolic extract and using HPTLC reported gallic acid 0.96%; protocatechuic acid 0.05%; and quercetin 0.40%. Saikia et al. (2016) analyzed phenolic profiles obtained by different extraction methods (previously mentioned). The phenolic compounds identified and quantified were: gallic acid between 4.89 ± 0.03 mg/L and 11.68 ± 0.05 mg/L; catechin from 2.90 ± 0.04 mg/L to 5.26 ± 0.07 mg/L; caffeic acid 1.96 ± 0.03 mg/L to 2.33 ± 0.05 mg/L; chlorogenic acid 2.17 ± 0.06 mg/L to 5.15 ± 0.02 mg/L; syringic acid 3.51 ± 0.03 mg/L to 9.74 ± 0.07 mg/L; ferulic acid 4.21 ± 0.06 mg/L to 18.83 ± 0.08 mg/L; coumaric acid 2.36 ± 0.05 mg/L to 2.81 ± 0.02 mg/L and quercetin 0.66 ± 0.2 mg/L to 0.65 ± 0.03 mg/L, by HPLC. In this study, the different extraction processes resulted in a higher concentration of compounds, as well as the detection of other phenolic compounds in addition to those found in fresh fruit juice. In some cases, however, the phenolic compounds were oxidized. This is due to the thermodilability in some compounds under temperatures used in each of the extraction methods. The detection of other compounds is also influenced by the extraction method, which causes the separation of the compounds of interest from the plant matrix, or which are bound to other components such as proteins, lipids and carbohydrates (Kopjar et al., 2014).

8 Conclusion

The phenolic compounds reported in the fruit of A. carambola L. are: (-) epicatechin, proanthocyanidins, gallic acid, 4-hydroxycinnamic acid, 4-hydroxy-3-methoxycinnamic, 3,5-dimethoxybenzoic acid, apigenin, kaempferol, luteolin, naringenin, morine, quercetin, myricetin, catechin, vanillic acid, caffeic acid, chlorogenic acid, p-cumaric acid, ellagic acid, protocatechuic acid, p-hydroxybenzoic acid, syringic acid, ferulic acid, rutin, protocatechuic acid trimer and sinapic acid tetramer, reported in aqueous extracts, alcoholic extracts, and extracts prepared with diethyl ether and in fruit juice. However, the phenolic profile varies in most of the studies surveyed, due to various factors that involve geolocation, agro-climatic conditions, sample maturation, post-harvest treatment, as well as the various extraction methodologies and the use and mixtures of different solvents. These variables differ in each of the studies conducted to determine phenolic compounds and antioxidant capacity. In general, however, it can be said that the fruit of A. carambola L. contains high concentrations of TPC and TFC compared to other edible tropical fruits, and is thus a fruit with a high antioxidant capacity.

Acknowledgements

The review was supported by the Fund for Strengthening Research at the Autonomous University of Queretaro under Grant [Number FOIF-UAQ: FNN-2018-08]. Special thanks to the National Council of Science and Technology of Mexico (CONACYT) for the support of A. V.-M.

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Phenolic profile of *Averrhoa carambola* L.

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