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Genetic Diversity on Acerola Quality: A Systematic Review

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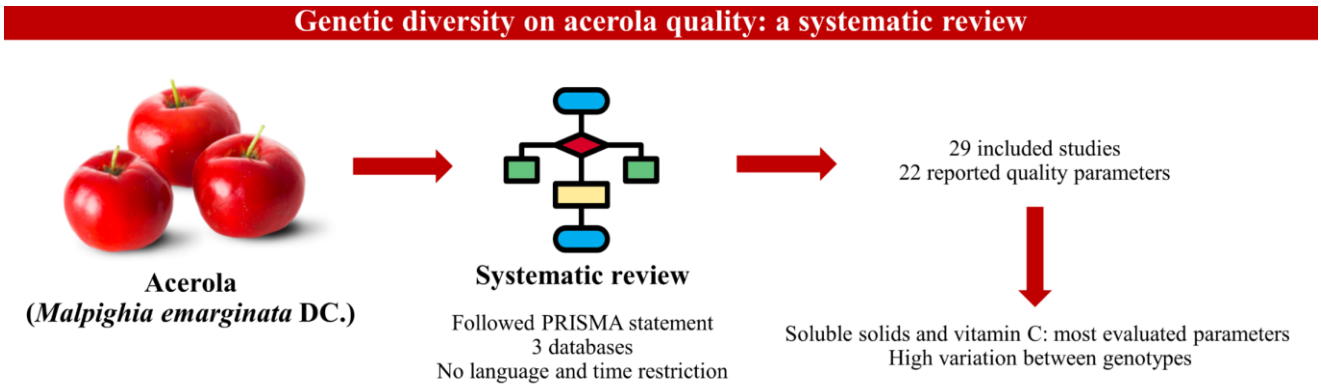
HIGHLIGHTS

- Acerola is a tropical super fruit with high vitamin C content.
- Acerola genotypes present great variability in quality traits.
- Acerola genotypes present high variability for physicochemical and antioxidant properties.
- Genetic diversity is useful for breeding programs and germplasm conservation.

Abstract: Acerola (*Malpighia emarginata* DC.) is a super-fruit with high ascorbic acid content and its quality can be highly affected by the genetic and environmental conditions. This systematic review aims to provide an overview of the influence of genetic variability on acerola quality traits. It was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) recommendations. PubMed, Scopus and SciELO electronic databases were searched using terms *acerola*, *selection*, and *genotypes*. 29 studies were selected after assessing articles for eligibility criteria, which reported data on 22 quality parameters. A high genetic diversity was observed for all quality traits. Soluble solids and ascorbic acid contents are the main parameters determined in studies with acerola. Titratable acidity, SS/TA ratio and pH are also evaluated in most studies. Different studies have already identified possible genotypes for use in acerola breeding programs based on fruit quality, both for launching new cultivars and for use as parents in crosses. Our review is a useful basis for acerola breeding programs and germplasm conservation. Future studies are required to further identify and quantify bioactive compounds in acerolas of different genotypes.

Keywords: *Malpighia emarginata* DC.; plant breeding; genotypes; breeding methods; fruit quality; vitamin C.

GRAPHICAL ABSTRACT



INTRODUCTION

Acerola (*Malpighia emarginata* DC.), also known as Barbados cherry and West Indian cherry, is a tropical fruit native to Central and South America and the Caribbean Islands. It is considered a super-fruit due to its high ascorbic acid (vitamin C) content, which is up to 100 times higher than the content observed in orange and lemon [1], in addition to phytochemicals such as phenolic compounds and carotenoids.

Global demand for acerola has been increasing due to the fruit attractive color, pleasant flavor, and nutraceutical potential. With high potential as a functional food, acerola may be consumed fresh or used in the processing industry [2]. Acerola has a high appealing economic prospect for growers to reach the specific markets of natural health-promoting products that maintain health and prevent degenerative diseases [3].

Fruit quality is defined by appearance, flavor, texture, and nutritional properties, which might be affected by several factors, including environmental conditions, crop management practices, maturity stage at harvest, storage conditions and genotype [4]. Fruit quality is measured through physical and chemical properties, which can also be used to characterize maturity stage and indicate when fruit are ready for consumption [5].

Brazil is the largest producer, consumer, and exporter of acerola, especially in tropical regions with high temperatures and high sunlight incidence, ideal for production of high-quality fruit. In most of the Brazilian commercial orchards of acerola, trees have been propagated by sexual methods, which result in a high genetic variability and high orchard heterogeneity, since this crop has predominantly cross-pollination [6–8].

Genetic diversity is one of main factors that defines acerola quality traits, such as color, weight, soluble solids, acidity, and ascorbic acid [9]. According to Magalhães and coauthors [10], the need for acerola genetic breeding results from the lack of established commercial cultivars with high fruit quality and yield. The high genetic variability in acerola has stimulated the development of breeding programs [11], essential for the preservation of biodiversity and the maintenance of genetic variability for future development of new genotypes.

Considering the importance of acerola as a crop species, this systematic review aims to provide an overview about the influence of genetic variability on acerola quality traits.

MATERIAL AND METHODS

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [12]. Two reviewers independently performed a bibliographic search in PubMed, Scopus, and SciELO electronic databases. The literature search was performed using the keywords *acerola*, *selection,* and *genotypes*. The word *acerola* was accomplished by Boolean operator "OR" and its scientific name (i.e., *Malpighia emarginata*, synonyms *Malpighia glabra* and *Malpighia punicifolia*) and it was combined one-to-one with all other terms. References comprising both titles and abstracts were exported to Mendeley.

No restriction was applied to language and time limit on search. The last search was performed on July 2nd, 2022. Studies were included in the selection if they met all the following criteria: (1) were articles published on peer-reviewed scientific journals; (2) evaluated acerolas (whole fruits) in ripe maturity stage, i.e., fruits with the skin completely covered with red color; and (3) evaluated at least one identified genotype. Exclusion criteria for study selection consisted of: (1) reviews, systematic reviews, meta-analyses, letters, conference abstracts, book chapters, personal opinions and articles of non-peer-reviewed journals; (2) evaluates acerola by-products or fruits in early maturity stages (green or intermediate stages); and (3) do not identify the genotype.

Potentially relevant articles were screened independently by two reviewers, initially by abstract and then by full text. Disagreements among reviewers were resolved by a third reviewer. Two authors independently used a standard data form to extract the relevant study information, including: author(s), publication year, Köppen's climate in study area, number of genotypes, and main values of physicochemical and antioxidant traits evaluated in the studies.

RESULTS

Study selection and characterization

The initial search through three electronic databases resulted in 1462 journal articles. Records were reduced for 1182 when duplicates were discarded. Of these latter, 40 articles were selected for full-text reading, and 29 were included in final review (Figure 1). Journal articles excluded from reading the title were n = 1095 and the abstract were n = 47. Articles excluded after full text review were n = 11: six for not presenting the studied genotype, one for characterizing only the industrial waste (bagasse) and not the fruits, one for characterizing only the isoenzymatic data and not the fruits, two for studying the repeatability of characteristics of the acerola in plants of unidentified genotypes and one for evaluating unripe fruits.

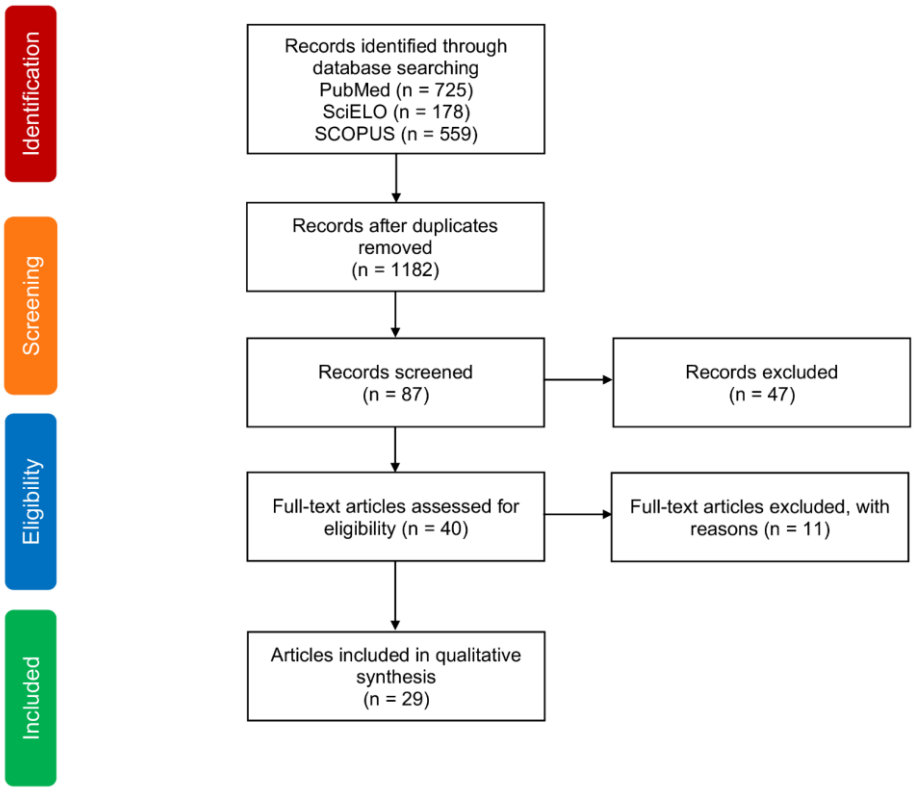


Figure 1. PRISMA flow chart showing the process of literature search and study selection.

Information on 22 physical, chemical and antioxidant properties of acerola were found and extracted from selected studies, namely soluble solids (SS), titratable acidity (TA), SS/TA ratio, pH, ascorbic acid, weight, diameter, length, color (expressed as lightness, *a**, *b**, chroma and hue angle), firmness, pulp yield, moisture, reducing sugars, anthocyanins, yellow flavonoids, carotenoids, total phenolic compounds, and total flavonols (Table 1).

The number of genotypes identified in the studies varied between 1 and 103. 'Flor Branca', 'Okinawa' and 'Olivier' were the most evaluated genotypes, being present in seven, seven, and six studies, respectively. In the studies included in the systematic review, five types of climates were found, according to Koppen's classification: seven studies in As climate and six in Aw climate, both characterized as tropical savanna with drier season in summer (As) or in winter (Aw); six studies in Bsh climate (hot and dry semi-arid); six studies in Cwa climate and four studies in Cfa climate, both characterized by subtropical climates with hot summer, with dry winter (Cwa) or without dry season (Cfa).

Table 1. Characteristics of studies included in the systematic review assessing genetic diversity of acerola.

Reference	Study location	Climate	Genotypes	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Adriano et al., 2011 [13]	Junqueirópolis, SP	Cwa	1	x[1]	x	x	x	x				x	x	x	x	x				x					
Batista et al., 2015 [14]	Petrolina, PE	Bsh	4	x	x	x	x		x	x	x	x			x	x	x								
Batista et al., 2018 [15]	Petrolina, PE	Bsh	4					x													x	x		x	x
Caetano et al., 2012 [16]	Junqueirópolis, SP	Cwa	1	x	x	x	x	x											x	x					
Carpentieri-Pípolo et al., 2000 [17]	Londrina, PR	Cfa	14	x				x	x	x	x							x							
Carpentieri-Pípolo et al., 2002 [18]	Londrina, PR	Cfa	3	x				x	x									x							
Cavalcante et al., 2007 [8]	Jaboticabal, SP	Cwa	16	x	x	x		x	x	x	x							x							
Farinelli et al., 2021 [19]	Mal. Cândido Rondon, PR	Cfa	103	x	x	x	x	x	x	x	x	x	x	x				x						x	
Ferreira et al. 2021 [20]	Petrolina, PE	Bsh	7	x	x	x	x	x	x			x	x	x	x	x				x	x		x	x	
Ferreira et al., 2022 [2]	Petrolina, PE	Bsh	35	x	x	x		x	x	x		x			x	x	x								
Gomes et al., 2000 [21]	Itápolis, SP	Aw	12	x			x	x	x	x	x							x							
Lima et al., 2000 [22]	Carpina, PE	Aw	6																		x		x		
Lima et al., 2005 [23]	Carpina, PE	Aw	12																					x	x
Maciel et al., 2010 [24]	Carpina, PE	As	18	x	x	x	x	x										x			x		x		
Magalhães et al., 2018 [10]	Jequitibá, MG	Cwa	24	x	x	x	x	x	x	x	x							x	x						
Mamede et al., 2009 [25]	Cruz das Almas, BA	As	3	x	x	x	x	x	x	x															
Mariano-Nasser et al., 2017 [26]	Adamantina, SP	Cwa	8	x	x		x	x				x			x	x				x		x		x	
Matsuura et al., 2001 [27]	Cruz das Almas, BA	As	12	x	x	x	x	x																	
Moura et al., 2007 [6]	Fortaleza, CE	Aw	45	x	x	x	x	x	x								x				x				x
Musser et al., 2004 [28]	Carpina, PE	As	12	x	x	x	x	x													x		x		
Musser et al., 2005 [29]	Carpina, PE	As	12						x	x	x														
Nasser et al., 2018 [30]	Adamantina, SP	Cwa	7	x	x		x	x																	
Nogueira et al., 2002 [31]	Paudalho, PE	As	2	x			x	x	x	x	x														
Reis et al., 2017 [32]	Petrolina, PE	Bsh	1	x	x		x	x											x						
Ribeiro & Freitas, 2020 [33]	Petrolina, PE	Bsh	2	x	x			x								x	x				x				
Rosso & Mercadante, 2005 [34]	Campinas, SP	Cfa	2																						x
Semensato & Pereira, 2000 [35]	Anápolis, GO	Aw	9	x			x	x	x	x	x								x						
Souza et al., 2014 [36]	Pacajús, CE	Aw	3	x	x	x	x	x												x	x	x		x	
Viana et al., 2021 [37]	Cruz das Almas, BA	As	3	x	x	x	x	x				x			x	x			x	x				x	x

[1] The *x* represents quality parameters evaluated in each included study. 1. Soluble solids (SS); 2. Titratable acidity (TA); 3. SS/TA ratio; 4. pH; 5. Ascorbic acid; 6. Weight; 7. Diameter; 8. Length; 9. Lightness; 10. *a**; 11. *b**; 12. Chroma; 13. Hue angle; 14. Firmness; 15. Pulp yield; 16. Moisture; 17. Reducing sugars; 18. Anthocyanins; 19. Yellow flavonoids; 20. Total flavonols; 21. Total phenolic compounds; 22. Carotenoids.

Soluble solids, titratable acidity, SS/TA ratio, and pH

Soluble solids (SS), titratable acidity (TA), SS/TA ratio, and pH were evaluated in 83%, 66%, 52%, and 66% of the included studies, respectively (Table 1).

SS content of acerola genotypes varied between 5.2% and 15.8%, with mean values in each study ranging between 6.4% and 11.0% (Figure 2A). The lowest TA was 0.37 g of malic acid per 100 g, while the maximum TA was 3.82 g 100 g^{-1}. The mean TA in most of studies ranged between 0.78 and 1.70 g 100 g^{-1}, with exception of two studies (3.07 and 3.14 g 100 g^{-1}) (Figure 2B).

In the 15 studies that evaluated SS/TA ratio, minimum and maximum values for this parameter were 1.86 and 19.39, respectively. The mean SS/TA ratio ranged between 2.41 and 9.46 (Figure 2C). The pH of acerola genotypes varied between 2.34 and 4.36 in selected studies, with a range of mean pH values of 2.78–3.68 (Figure 2D).

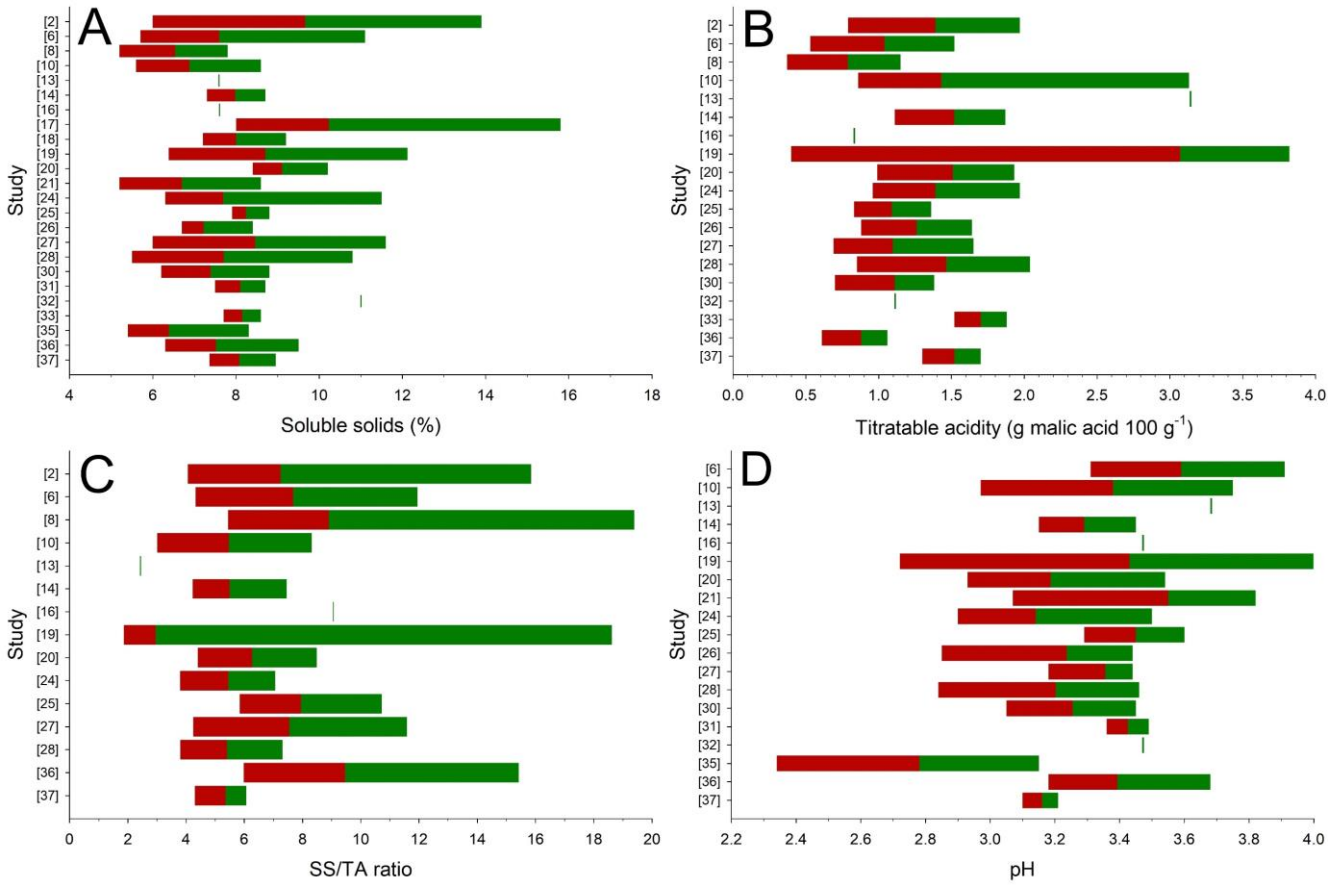


Figure 2. Soluble solids (SS) (A), titratable acidity (TA) (B), SS/TA ratio (C), and pH (D) of acerola genotypes as reported in selected studies. The red and green areas in the bars represent genotypes with lower and higher values than the general mean of the physicochemical property in each study, respectively. For studies with only one genotype evaluated, the mean is represented by a vertical line.

Ascorbic acid, weight, diameter, and length

The ascorbic acid content of acerolas was reported in 24 studies, which corresponds to 83% of included studies. Ascorbic acid content varied between 348 and 2800 mg per 100 g in acerola genotypes.

Weight, diameter, and length were the most evaluated physical parameters in acerola genotypes, with results reported in 14, 11, and 9 included studies, respectively (Table 1).

Weight of acerola genotypes ranged between 1.53 g and 15.02 g, which represents a maximum weight 9.8 times greater than the minimum value. Mean weight had a variation between 4.08 g and 9.99 g (Figure 3B). Diameter (also called transversal diameter) had minimum and maximum values between 0.83 cm and 3.00 cm, respectively, with a range of mean values of 1.21–2.63 cm (Figure 3C). Length (or longitudinal diameter) varied between 0.94 cm and 2.92 cm, with mean values between 1.51 cm and 2.18 cm (Figure 3D).

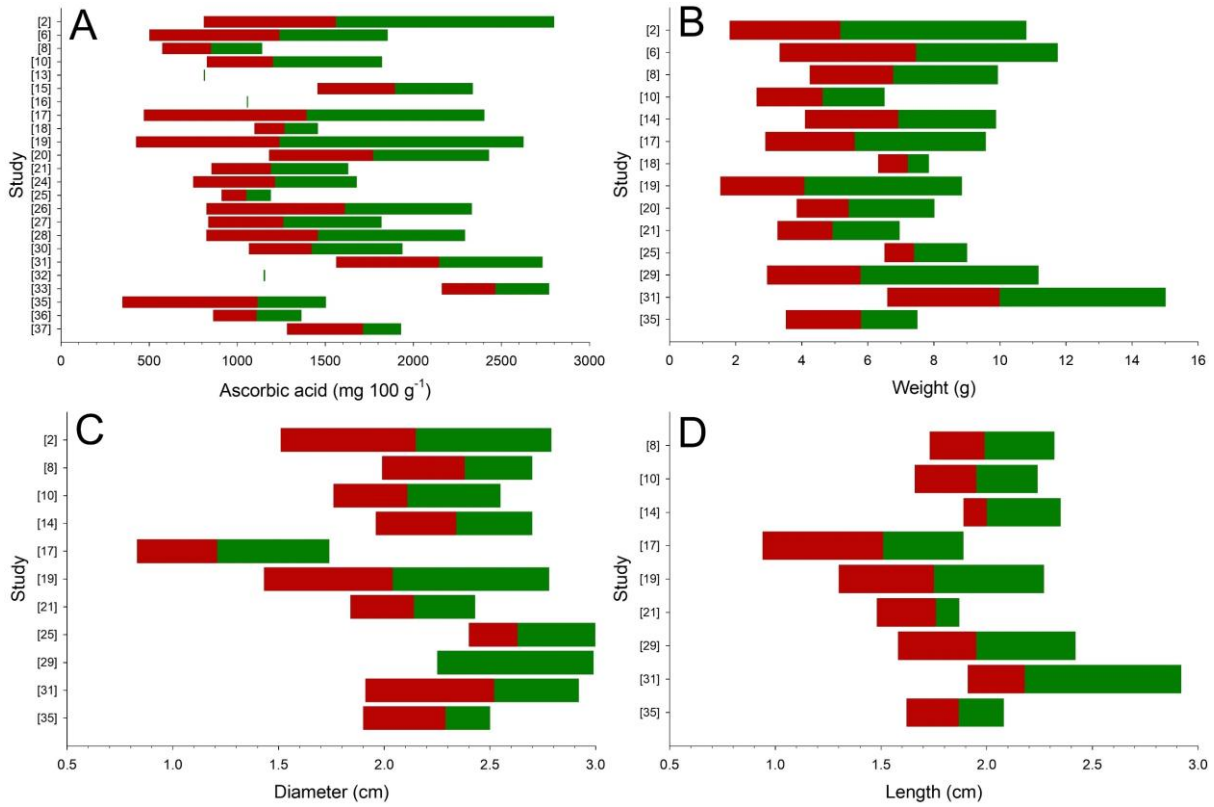


Figure 3. Ascorbic acid (A), weight (B), diameter (C), and length (D) of acerola genotypes as reported in selected studies. The red and green areas in the bars represent genotypes with lower and higher values than the general mean of the physicochemical property in each study, respectively. For studies with only one genotype evaluated, the mean is represented by a vertical line.

Color, firmness, pulp yield, and moisture

The lightness was the most reported color parameter in selected studies, with seven results indicating a range between 19.40 and 55.90. Chroma and hue angle of acerola genotypes were quantified in six and seven studies, respectively, with variations of 16.36–55.84 and 9.17–60.80. The color spaces *a** and *b** were evaluated in three studies, with ranges of 11.30–46.60 and 3.00–48.90, respectively (Table 2).

Table 2. Color parameters, firmness, pulp yield and moisture of acerola genotypes as reported in selected studies.

Ref	Lightness	*a**	*b**	Chroma	Hue angle	Firmness (N)	Pulp yield (%)	Moisture (%)
[2]	32.47–51.83	-	-	27.66–53.29	19.45–45.82	5.02–20.02	-	-
[6]	-	-	-	-	-	2.56–6.48	-	-
[8]	-	-	-	-	-	-	38.58–61.21	-
[10]	-	-	-	-	-	-	67.17–81.76	90.04–92.36
[13]	40.12	37.16	21.70	43.15	30.08	-	-	-
[14]	20.48–23.68	-	-	16.36–22.33	9.17–14.04	2.14–2.62	-	-
[16]	-	-	-	-	-	-	-	92.49
[17]	-	-	-	-	-	-	61.36–86.18	-
[18]	-	-	-	-	-	-	72.10–82.50	-
[19]	19.40–55.90	11.30–46.60	3.00–48.90	-	-	-	57.20–90.10	-
[20]	33.18–44.22	36.14–46.20	12.95–29.98	38.64–55.07	19.00–32.98	-	-	-
[21]	-	-	-	-	-	-	47.80–58.90	-
[24]	-	-	-	-	-	-	53.17–72.54	-
[25]	-	-	-	-	-	-	-	-
[26]	23.30–31.80	-	-	19.45–33.70	13.10–26.10	-	-	-
[29]	-	-	-	-	-	-	-	-
[31]	-	-	-	-	-	-	-	-
[32]	-	-	-	-	-	-	-	90.75
[33]	-	-	-	-	24.90–60.80	13.60–19.20	-	-
[35]	-	-	-	-	-	-	-	90.67–93.30
[37]	34.48–37.71	-	-	43.43–55.84	21.31–30.08	-	-	91.86–93.86

Dash-separated values indicate the minimum and maximum for each parameter. In lines without a dash, the value represents the mean in studies with only one genotype evaluated.

The pulp firmness of acerolas varied between 2.14 N and 20.02 N in four reported studies. Pulp yield and moisture had ranges of 38.58-90.10% and 90.04-93.86%, respectively, in the seven and five studies that reported these parameters (Table 2).

Reducing sugars and bioactive compounds

Reducing sugars content of acerola genotypes was evaluated in six reported studies, with a minimum value of 2.32% and a maximum of 6.03% (Table 3).

Table 3. Reducing sugars and bioactive compounds of acerola genotypes as reported in selected studies.

Ref	Reducing sugars (%)	Anthocyanins (mg 100 g^{-1})	Yellow flavonoids (mg quercetin equivalent 100 g^{-1})	Total flavonols (mg quercetin equivalent 100 g^{-1})	TPC (mg 100 g^{-1})	Carotenoids (mg β-carotene 100 g^{-1})
[6]	-	1.52–28.47	-	-	-	0.34–8.41
[10]	-	-	-	-	-	-
[13]	5.73	-	-	-	-	-
[15]	-	7.03–13.80	6.80–10.73	-	850.26–1345.21[b]	1.62–3.28
[16]	5.17	-	-	-	-	-
[19]	-	-	-	-	84.00–3196.00[b]	-
[20]	2.57–3.80[a]	14.99–68.23[a]	-	3.92–8.96[a]	1188.46–2590.40[b]	-
[22]	-	14.06–50.98	-	9.31–20.22	-	-
[23]	-	-	-	-	737.00–1888.00[c]	0.94–4.06
[24]	-	4.35–14.93	-	4.40–15.04	-	-
[26]	2.89–4.24	-	3.56–12.34	-	914.20–2428.30[b]	-
[28]	-	2.40–55.80	-	5.90–22.20	-	-
[32]	-	-	-	-	-	-
[33]	-	6.79–7.28	-	-	-	-
[34]	-	-	-	-	-	3.71–18.81[a]
[35]	-	-	-	-	-	-
[36]	2.32–6.03	5.07–12.37	7.36–9.82	-	1561.67–2631.34[b]	-
[37]	3.56–4.97	-	-	-	410.82–764.22[b]	0.45–1.58

TPC: Total phenolic compounds. [a]Quantified in high-performance liquid chromatography. [b]Expressed as gallic acid equivalent. [c]Expressed as catechin equivalent. Dash-separated values indicate the minimum and maximum for each parameter. In lines without a dash, the value represents the mean in studies with only one genotype evaluated.

For bioactive compounds, the number of studies per variable ranged from three for yellow flavonoids, to eight for anthocyanins. Even with the low number of studies reporting these variables, a large variation was observed between genotypes regarding the anthocyanins, yellow flavonoids, carotenoids, total flavonols, and total phenolic compounds (Table 3).

Anthocyanin content varied between 1.52 mg 100 g^{-1} and 68.23 mg 100 g^{-1}. Contents of yellow flavonoids and total flavonols had ranges of 3.56–12.34 mg of quercetin equivalent 100 g^{-1} and 3.92–22.20 mg of quercetin equivalent per 100 g^{-1}, respectively (Table 3).

Total phenolic compounds (TPC) content of acerola geno types ranged between 84.00 and 3196.00 mg of equivalent gallic acid (GAE) per 100 grams. Carotenoids were quantified in five included studies and varied between 0.34 and 18.81 mg β-carotene 100 g^{-1} (Table 3).

DISCUSSION

Among the tropical fruits, acerola is a highly attractive exotic fruit with high ascorbic acid content, adapted to different edaphoclimatic conditions with high potential for industrial use, which has been attracting the interest of fruit growers [31].

Brazil is the largest producer, consumer, and exporter of acerola. However, even with the production potential of this crop in Brazil, the implantation of commercial acerola orchards is considered recent, when compared to other fruit species, being formed mostly by plants with unidentified genetics, and which in most cases, do not present agronomic and commercial characteristics desirable for the fresh market. High genetic variability in commercial acerola orchards is a result of seed propagation, characterizing them as highly heterogeneous in terms of fruit quality and quantity, which takes place due to the lack of new genotypes with improved quality traits for fresh market [10].

Even with the importance of acerola as a crop species, this is the first time in the literature that data from quality of different acerola genotypes are gathered and discussed. From a systematic search and selection of peer-reviewed articles published in journals indexed to databases, we extracted information from 29

studies related to 22 physicochemical attributes and bioactive compounds of acerola from different genotypes.

In the selected studies, the number of evaluated genotypes varied between 1 and 103. ‘Flor Branca’, ‘Okinawa’ and ‘Olivier’ were the most present, in at least five studies each. ‘Flor Branca’ and ‘Okinawa’ are among the main acerola varieties produced in the São Francisco Valley (SFV) [38], which is the main acerola producing mesoregion in Brazil, occupying about 1/4 of the cultivated area with the crop in the country. Ideal edaphoclimatic conditions for acerola fruit development, including high solar radiation and high temperatures throughout the year, associated with the short cycle of 3–4 weeks between flowering and harvest, allow the production of up to eight annual crops in the SFV under irrigation [20].

'Flor Branca' is a cultivar with good productivity and high production regularity, characterized by low vigor plants and small fruits (<5 g). The fruits have low flesh firmness and high sensitivity to mechanical damage during handling and transport, as well as a very short shelf life [38]. ‘Okinawa’ acerolas are usually higher than other cultivars (5–9 g), with an attractive purple color and high ascorbic acid contents [39–40]; however, this cultivar presents low productivity and production irregularity as limiting factors.

Selected studies were classified in five different Köppen’s climate conditions, including tropical savanna climate with a drier season in summer (As) or in winter (Aw), hot and dry semi-arid (Bsh), and subtropical climates with hot summer, with dry winter (Cwa) or without dry season (Cfa). Although the regions of the studies belong to three distinct climatic zones (A, B and C), all of them have high temperatures (≥18 °C) as a common factor, either throughout the year (A and B zones), or at least one month a year (C zone) [41]. As a typical species of tropical climate, acerola grows in temperatures between 15 °C and 32 °C and is well adapted to temperatures around 26 °C [42].

Soluble solids (SS) and ascorbic acid contents were the most reported quality traits, both present in 83% of selected studies. SS content represent substances that can be dissolved in water, mainly soluble sugars, influencing on sweetness perception by consumers. Thus, the selection of genotypes with high SS is essential in acerola breeding programs for fresh consumption [27]. Average SS of acerola genotypes in the selected studies varied between 6.4% and 11.0%, close when compared to other fruits rich in vitamin C, such as guava [43], lemon [44], and strawberry [45–46]. Some importing countries require a minimum SS content in acerolas, such as the European Union (7.0° Brix) and Japan (7.5° Brix) [47].

Titratable acidity (TA) represents the organic acids that greatly affect fruit overall eating quality and flavor [48]. The major organic acid in acerolas is malic acid, although succinic, citric, and other acids are also detectable [20,49]. In selected studies, TA of genotypes ranged between 0.37 g and 3.82 g of malic acid 100 g^{-1}. Low pH values were observed in acerola genotypes, with a range of 2.34–4.36 in the selected studies. In general, acerola is a very acidic fruit, so low fruit acidity associated with high sugar content is essential for the release of successful commercial acerola cultivars for fresh consumption [3]. The combined perception of sweetness and sourness (acidity), expressed through the SS/TA ratio, is a useful practical indicative of flavor perception by consumers [8], whose minimum value of 10 is established for acerolas intended to fresh consumption [47].

A wide range of 1.86–19.39 was observed for SS/TA ratio in selected studies, but few genotypes showed a SS/TA ratio greater than 10. ‘Florida Sweet’ acerola evaluated by Souza and coauthors (2014) [36] showed a high SS/TA ratio of 15.42, in contrast to the values below 7 observed in the other evaluated cultivars (‘Flor Branca’ and ‘BRS 366’). Ferreira and coauthors [2] observed that 'BRS Rubra' was the only genotype among 35 evaluated in two production cycles that presented SS/TA greater than 10, confirming a previous result by Mamede and coauthors [25]. ‘Florida Sweet’ is a well-established acerola cultivar selected in Florida, USA, and available since the mid-1950s, outstanding for its high sugar and low acid contents. In 2004, the Brazilian acerola cultivar 'BRS Rubra' was released with the same intention to meet the demand for fruits for fresh consumption with a high SS/TA ratio.

Mean values of ascorbic acid content in acerola genotypes were higher than 1000 mg 100 g^{-1} in all studies, except in those by Adriano and coauthors (810 mg 100 g^{-1}) [13] and Cavalcante and coauthors (852 mg 100 g^{-1}) [8]. Ascorbic acid is an essential nutrient for the human diet, playing a key role on formation of blood vessels, cartilage, muscle, and bone collagen, in addition to improving the immune system and aiding in the absorption of iron [50]. Ascorbic acid is also one of the most important water-soluble antioxidants in fruits. Acerola is the second richest natural source of ascorbic acid in the world, only comparable to the native Amazonian fruit camu-camu (*Myrciaria dubia*, Myrtaceae) [51]. Siqueira and coauthors [52] compared the costs of nutrients provided by typical foods found in the Brazilian diet and found that vitamin C is the cheapest nutrient in Brazil, considering that with only 3.3 Brazilian Real cents (≅USD 0.0067) it is possible to supply the whole daily needs of this nutrient by consuming acerola juice.

Weight of acerola genotypes ranged between 1.53 g and 15.02 g, which represents a maximum weight 9.8 times greater than the minimum value. For fruit diameter and length, also known as transversal and

longitudinal diameters, the ranges were 0.83–3.00 cm and 0.94–2.92 cm, respectively. Acerola fruit is a thin-skinned, three-lobed small globose drupe [42]. High variations in acerola physical traits are intrinsic to genetic materials and their interaction with different edaphoclimatic conditions of the crop environments [10]. Fruit dimension is an important trait for acerola selection, since the larger the fruit, the easier and faster the harvesting, reducing required labor and production costs [14].

As an important quality trait for consumers and a major criterion used to assess fruit maturity, the color of acerola changes from bright glossy green to darkish-red or purple throughout fruit development due to chlorophyll degradation concomitant with a rise in the synthesis of carotenoids and anthocyanins [42]. The presence of these pigments in ripe fruit of different genotypes was reported by the high values of color spaces a* (11.30–46.60) and b* (3.00–48.90) and low hue (9.17–60.80°).

Pulp firmness of acerolas varied between 2.14 N and 20.02 N, which represents a difference of 9.4 times between genotypes with minimum and maximum firmness. Acerola is considered a highly perishable fruit, with high respiration rate and ethylene production [3]. Both factors trigger an intense fruit softening after harvest that reduce fruit quality [53]. Thus, the selection of acerola genotypes with higher pulp firmness and short time between harvesting the fruit and reaching the consumer are essential for the fruit to present high quality.

Pulp yield showed a high variation between genotypes (38.58–90.10%). The low pulp yield is not a characteristic that makes it impossible to use a fruit species for fresh consumption or industrial processing, although higher values are desirable to reduce cost/benefit ratio [24]. Fruit moisture was higher than 90% in all genotypes, while reducing sugars content ranged between 2.32% and 6.03%. Reducing sugars of acerola are mainly composed of fructose and glucose and are responsible for the sweetness of the fruit. Santos and coauthors [53] quantified sugars in acerola through nuclear magnetic resonance spectroscopy and found that glucose and fructose were predominant and accumulated in ripe fruit, while sucrose exhibited a slight increase during ripening.

Acerola is a ‘superfruit’ due to presence of phytochemicals with antioxidant, astringent, anti-viral, anti-carcinogenic, anti-inflammatory, antianemics, and antifungal properties [9]. Anthocyanin content had a large variation of 45 times between genotypes with minimum (1.52 mg 100 g^{-1}) and maximum (68.23 mg 100 g^{-1}) values. Large differences between studies regarding the anthocyanin content of acerola genotypes tend to be related to the procedures of laboratory analysis, since the determination of these pigments involves the use of reagents and equipment. Even so, the high intra-study variation in anthocyanin content confirms that the concentration of this pigment is highly genotype-dependent, as pointed out by Ferreira and coauthors [20]. The anthocyanin content directly impacts the color of red-ripe acerolas, which can vary from orange to dark purple, and the fruit antioxidant activity, since anthocyanins are the major phenolic compounds in ripe fruit, and therefore, can reduce oxidative damage caused by free radicals to the human organism.

High variations were also observed for contents of carotenoids (0.34–18.81 mg β-carotene 100 g^{-1}), yellow flavonoids (3.56–12.34 mg quercetin equivalent 100 g^{-1}), total flavonols (3.92–22.20 mg of quercetin equivalent 100 g^{-1}), and total phenolic compounds (TPC) (84.00–3196.00 mg of gallic acid equivalent 100 g^{-1}). Acerola is a remarkable functional food resource with high levels of phenolic compounds. Phenolic compounds are important for plant metabolism and have been stated as important molecules for human organism due to their health characteristics, particularly related to their antioxidant power [42].

High variability in acerola quality has been reported in Brazilian orchards, especially those propagated by seeds, which motivated the selection of superior genotypes with desired agronomic traits and fruit quality [7]. Acerola quality is highly associated with genetic factors, but also by environmental factors such as precipitation, solar radiation, and temperature, and by preharvest factors such as irrigation, fertilization, and control of pests and diseases [42].

Studies carried out with acerola clones and accessions using different molecular markers, including Inter Simple Sequence Repeats (ISSR) [54] and Random Amplified Polymorphic DNA (RAPD) [55–56] primers, revealed a high genetic variability.

CONCLUSION

With a continuous rise in global demanding of acerolas, there is a need for the characterization of their key quality traits. In the present review, we systematically identified a high genetic diversity on all acerola quality traits. Soluble solids and ascorbic acid contents are the main parameters determined in studies with acerola. Titratable acidity, SS/TA ratio and pH are also evaluated in most studies. Different studies have already identified possible genotypes for use in acerola breeding programs based on fruit quality, both for launching new cultivars and for use as parents in crosses. Our review is a useful basis for acerola breeding

programs and germplasm conservation. Future studies are required to further identify and quantify bioactive compounds in acerolas of different genotypes.

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REFERENCES

1. Prakash A, Baskaran R. Acerola, an untapped functional superfruit: a review on latest frontiers. J. Food Sci. Technol. 2018;55(9):3373–84.
2. Ferreira MAR, Vilvert JC, Silva BOS, Ferreira IC, Souza FF, Freitas ST. Multivariate selection index of acerola genotypes for fresh consumption based on fruit physicochemical attributes. Euphytica. 2022;218:25.
3. Delva L, Schneider RG. Acerola (*Malpighia emarginata* DC): Production, postharvest handling, nutrition, and biological activity. Food Rev. Int. 2013;29(2):107–26.
4. Belwal T, Devkota HP, Hassan HA, Ahluwalia S, Ramadan MF, Mocan A, et al. Phytopharmacology of acerola (*Malpighia* spp.) and its potential as functional food. Trends Food Sci. Technol. 2018;74:99–106.
5. Vilvert JC, Freitas ST, Ferreira MAR, Costa EBS, Aroucha EMM. Sample size for postharvest quality traits of 'Palmer' mangoes. Rev. Bras. Frut. 2021;43(5):e014.
6. Moura CFH, Alves RE, Figueiredo RW, Paiva JR. [Physical and physical-chemical evaluations of fruits of West Indian cherry (*Malpighia emarginata* D.C.) clones]. Cienc. Agron. 2007;38(1):52–7. Brazilian Portuguese.
7. Ritzinger R, Ritzinger CHSP, Fonseca N, Machado CF. Advances in the propagation of acerola. Rev. Bras. Frut. 2017;40(3):e928.
8. Cavalcante ÍHL, Beckmann MZ, Martins ABG, Campos MCC. Preliminary selection of acerola genotypes in Brazil. Fruits. 2007;62(1):27–34.
9. Nunes RS, Kahl VFS, Sarmento MS, Richter MF, Abin-Carriquiry JA, Martinez MM, et al. Genotoxic and antigenotoxic activity of acerola (*Malpighia glabra* L.) extract in relation to the geographic origin. Phytother. Res. 2013;27(10):1495–501.
10. Magalhães DS, Rufni JCM, Alburquerque AS, Viol RE, Fagundes MCP, Menezes TP. Genetic diversity among accessions of acerola based on the quality of fruits. Comun. Sci. 2018;9(2):133–41.
11. Lima EN, Araujo MEB, Bertini CHCM, Moura CFH, Hawerroth MC. [Genetic diversity of clones of acerola assessed by ISSR molecular markers]. Comun. Sci. 2015;6(2):174–80. Brazilian Portuguese.
12. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: Explanation and elaboration. BMJ. 2009;339:b2700.
13. Adriano E, Leonel S, Evangelista RM. [Fruit quality of Barbados cherry trees cv. Olivier in two stages of maturity]. Rev. Bras. Frut. 2011;33(spe1):541–5. Brazilian Portuguese.
14. Batista PF, Lima MAC, Trindade DCG, Alves RE. Quality of different tropical fruit cultivars produced in the lower basin of the São Francisco Valley. Cienc. Agron. 2015;46(1):176–84.
15. Batista PF, Lima MAC, Alves RE, Façanha RV. Bioactive compounds and antioxidant activity in tropical fruits grown in the lower-middle São Francisco Valley. Cienc. Agron. 2018;49(4):616–23.
16. Caetano PK, Daiuto ÉR, Vieites RL. [Physicochemical and sensory characteristics of jam produced with acerola pulp and juice]. Braz. J. Food Technol. 2012;15(3):191–7. Brazilian Portuguese.
17. Carpentieri-Pípolo V, Destro D, Prete CEC, Gonzales MGN, Popper I, Zanatta S, et al. [West Indian cherry parental genotype selection based on multivariate genetic divergence]. Pesqui. Agropecu. Bras. 2000;35(8):1613–9. Brazilian Portuguese.
18. Carpentieri-Pípolo V, Prete CEC, Gonzales MGN, Popper IO. [Three new Caribbean cherry (*Malpighia emarginata* DC) cultivars: UEL – 3 Dominga, UEL 4 – Ligia and UEL 5 – Natalia]. Rev. Bras. Frutic. 2002;24(1):124–6. Brazilian Portuguese.
19. Farinelli D, Portarena S, Silva DF, Traini C, Silva GM, Silva EC, et al. Variability of fruit quality among 103 acerola (*Malpighia emarginata* D. C.) phenotypes from the subtropical region of Brazil. Agriculture. 2021;11(11):1078.
20. Ferreira IC, Silva VP, Vilvert JC, Souza FF, Freitas ST, Lima MS. Brazilian varieties of acerola (*Malpighia emarginata* DC.) produced under tropical semi-arid conditions: Bioactive phenolic compounds, sugars, organic acids, and antioxidant capacity. J. Food Biochem. 2021;45(8):e13829.
21. Gomes JE, Perecin D, Martins ABG, Almeida EJ. [Phenotypic variability in west Indian cherry genotypes]. Pesqui. Agropecu. Bras. 2000;35(11):2205–11. Brazilian Portuguese.
22. Lima VLAG, Mélo EA, Lima LS, Nascimento PP. [Flavonoids in acerola (*Malpighia* sp. L.) selections. 1- Anthocyanins and flavonols content]. Cienc. Rural. 2000;30(6):1063–8. Brazilian Portuguese.
23. Lima VLAG, Mélo EA, Maciel MIS, Prazeres FG, Musser RS, Lima DES. Total phenolic and carotenoid contents in acerola genotypes harvested at three ripening stages. Food Chem. 2005;90(4):565–8.
24. Maciel MIS, Enayde M, Lima V, Souza KA, Silva W. [Physicochemical characterization of fruits from genotypes of acerola tree (*Malpighia emarginata* D.C.)]. Food Sci. Technol. 2010;30(4):865–9. Brazilian Portuguese.
25. Mamede MEO, Miranda MPS, Ritzinger R, Godoy RCB, Velozo ES. Physico-chemical and sensorial evaluation of new varieties of acerola. Br. Food J. 2009;111(4):387–95.
26. Mariano-Nasser FADC, Nasser MD, Furlaneto KA, Ramos JA, Vieites RL, Pagliarini MK. Bioactive compounds in different acerola fruit cultivares. Semin. Cienc. Agrar. 2017;38(4):2505–14.

27. Matsuura FCAU, Cardoso RL, Folegatti MIS, Oliveira JRP, Oliveira JAB, Santos DB. [Physicochemical evaluation in fruits from different genotypes of Barbados cherry (*Malpighia punicifolia* L.)]. Rev. Bras. Frutic. 2001;23(3):602–6. Brazilian Portuguese.
28. Musser RS, Lemos MA, Lima VLAG, Mélo EA, Lederman IE, Santos VF. [The physicochemical characteristics of acerola fruits from germoplasm active bank in Pernambuco]. Food Sci. Technol. 2004;24(4):556–61. Brazilian Portuguese.
29. Musser RS, Lemos MA, Lima VLAG, Mélo EA, Lederman IE, Santos VF. [Physical and production characteristics of acerola fruit from active germplasm bank in Pernambuco]. Rev. Bras. Frutic. 2005;27(2):320–3. Brazilian Portuguese.
30. Nasser MD, Mariano-Nasser FAC, Furlaneto KA, Ramos JA, Caetano PK. [Composition of the acerola of different genotypes in two seasons of harvest]. Nativa. 2018;6(1):15. Brazilian Portuguese.
31. Nogueira RJMC, Moraes JAPV, Burity HA, Silva Junior JF. [Physicochemical characteristics of Barbados cherry influenced by fruit maturation stage]. Pesqui. Agropecu. Bras. 2002;37(4):463–70. Brazilian Portuguese.
32. Reis DS, Figueiredo Neto A, Ferraz AV, Freitas ST. [Production and storage stability of acerola flour dehydrated at different temperatures]. Braz. J. Food Technol. 2017;20:e2015083. Brazilian Portuguese.
33. Ribeiro BS, Freitas ST. Maturity stage at harvest and storage temperature to maintain postharvest quality of acerola fruit. Sci. Hortic. 2020;260:108901.
34. Rosso VV, Mercadante AZ. Carotenoid composition of two Brazilian genotypes of acerola (*Malpighia punicifolia* L.) from two harvests. Food Res. Int. 2005;38(8–9):1073–7.
35. Semensato LR, Pereira AS. [Fruit characteristics of acerola genotypes grown at high altitude]. Pesqui. Agropecu. Bras. 2000;35(12):2529–36. Brazilian Portuguese.
36. Souza KO, Moura CFH, Brito ES, Miranda MRA. Antioxidant compounds and total antioxidant activity in fruits of acerola from cv. Flor Branca, Florida Sweet and BRS 366. Rev. Bras. Frutic. 2014;36(2):294–304.
37. Viana ES, Fonseca MD, Reis RC, Andrade MVS, Ritzinger R. Physicochemical and bioactive compound evaluation of acerola genotypes. Rev. Virtual Quim. 2021;13(4):993–8.
38. Souza FF, Deon MD, Castro JMC, Lima MAC, Rybka ACP, Freitas ST. Principais variedades de aceroleiras cultivadas no Submédio do Vale do São Francisco. Petrolina: Embrapa Semiárido; 2013. Brazilian Portuguese.
39. Maranhão Ribeiro CMC, Sousa TPA, Holschuh HJ, Ribeiro MTJB, Silva SM, Maciel MIS. Fruit development and ripening of acerola 'Okinawa' cultivar. Acta Hortic. 2018;1198:199–204.
40. Calgaro M, Braga MB, editors. A cultura da acerola. 3rd ed. Brasília: Embrapa; 2012. Brazilian Portuguese.
41. Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteorol. Zeitschrift. 2013;22(6):711–28.
42. Mohammed M. Acerola (*Malpighia emarginata* DC.). In: Yahia EM, editor. Postharvest biology and technology of tropical and subtropical fruits: Açai to citrus. Cambridge: Woodhead Publishing Limited; 2011. p. 27–47.
43. Cavalini FC, Jacomino AP, Trevisan MJ, Miguel ACA. [Harvest time and quality of 'Kumagai' and 'Paluma' guavas]. Rev. Bras. Frutic. 2015;37(1):64–72. Brazilian Portuguese.
44. Aguilar-Hernández MG, Sánchez-Rodríguez L, Hernández F, Forner-Giner MÁ, Pastor-Pérez JJ, Legua P. Influence of new citrus rootstocks on lemon quality. Agronomy. 2020;10(7):974.
45. Ariza MT, Miranda L, Gómez-Mora JA, Medina JJ, Lozano D, Gavilán P, et al. Yield and fruit quality of strawberry cultivars under different irrigation regimes. Agronomy. 2021;11(2):261.
46. Cecatto AP, Calvete EO, Nienow AA, Costa RC, Mendonça HFC, Pazzinato AC. Culture systems in the production and quality of strawberry cultivars. Acta Sci. Agron. 2013;35(4):471–8.
47. Ritzinger R, Ritzinger CHSP. Acerola. Inf. Agropec. 2011;32(264):17–25. Brazilian Portuguese.
48. Xu K, Wang A, Brown S. Genetic characterization of the Ma locus with pH and titratable acidity in apple. Mol. Breed. 2012;30(2):899–912.
49. Guedes TJFL, Rajan M, Barbosa PF, Silva ES, Machado TOX, Narain N. Phytochemical composition and antioxidant potential of different varieties viz. Flor Branca, Costa Rica and Junco of green unripe acerola (*Malpighia emarginata* D.C.) fruits. Food Sci. Technol. 2022;42:e46320.
50. Goldenberg L, Yaniv Y, Porat R, Carmi N. Mandarin fruit quality: a review. J. Sci. Food Agric. 2018;98(1):18–26.
51. Cunha-Santos ECE, Viganó J, Neves DA, Martínez J, Godoy HT. Vitamin C in camu-camu [*Myrciaria dubia* (H.B.K.) McVaugh]: evaluation of extraction and analytical methods. Food Res. Int. 2019;115:160–6.
52. Siqueira KB, Binoti ML, Nunes RM, Borges CAV, Pilati AF, Marcelino GW, et al. [Cost-benefit ratio of the nutrients of the food consumed in Brazil]. Cien. Saude Colet. 2020;25(3):1129–35. Brazilian Portuguese.
53. Santos CP, Batista MC, Saraiva KDC, Roque ALM, Miranda RS, Silva LMA, et al. Transcriptome analysis of acerola fruit ripening: insights into ascorbate, ethylene, respiration, and softening metabolisms. Plant Mol. Biol. 2019;101(3):269–96.
54. Lima EN, Araujo MEB, Bertini CHCM, Moura CFH, Hawerroth MC. [Genetic diversity of clones of acerola assessed by ISSR molecular markers]. Comun. Sci. 2015;6(2):174–80. Brazilian Portuguese.
55. Moraes Filho RM, Martins LSS, Musser RSS, Montarroyos AVV, Silva EF. Genetic variability in accessions of the acerola germplasm bank of Universidade Federal Rural de Pernambuco, Brazil. Genet. Mol. Res. 2013;12(4):5145–51.
56. Salla MFS, Ruas CDF, Ruas PM, Carpentieri-Pípolo V. [The use of molecular markers in the genetic variability analysis of acerola (*Malphighia emarginata*)]. Rev. Bras. Frutic. 2002;24(1):15–22. Brazilian Portuguese.