Chapter

Table Grapes: There Is More to Vitiviniculture than Wine…

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Abstract

Table grapes are fruits intended for fresh human consumption due to their sensory attributes and nutritional value. The objective of this chapter is to review the existing knowledge about table grapes, including a description of different varieties, with particular emphasis on the new highly appreciated seedless varieties. Following an introductory note on the world distribution and production of table grapes, also considering the impact of climate change, selected varieties of table grapes will be characterized in terms of their physiology, postharvest features, and consumer preferences. A morphological description of each variety, with emphasis on grape skin, grape rachis and grape cluster will be included. A final note on the drying of table grapes into raisins, and the most appropriate varieties for drying, will be given. The major changes occurring throughout the growth, development, and ripening phases of table grapes production will be discussed, regarding both physical (skin color and skin and pulp texture) and chemical (phenolic compounds, sugar content and acidity) parameters, as well as growth regulators.

Keywords: grapes, varieties, seedless, raisins, quality, consumer

1. Introduction

Table grapes are destined for fresh human consumption because of their sensory, nutritional, and commercial attributes, which is in line with the definition adopted for table grapes by the *International Organization of Vine and Wine* [1] "A fresh grape, produced from special vine varieties or vine varieties cultivated for this purpose and destined for consumption as such, basically because of its sensory and commercial characteristics."

The consumption of the grapes can be fresh, or derived products such as juices, wines, raisins, and has increased due to the identification of beneficial compounds for human health in its constitution [2].

The culture of the vine is one of the most important agricultural crops in the world. The world production of grapes intended for all uses, in 2018, was 77.8 million tons, 57% wine grapes, 36% table grapes and 7% dried grapes [3]. In 2018 the world production of table grapes was 27.3 million tons (**Figure 1**).

In 2020, the world area planted with vines for all purposes, wine, juices, table grapes and raisins, is estimated at 7.3 million hectares. An apparent stabilization hides the reduction in the vineyard surface in Iran, Turkey, Portugal, Uzbekistan, and USA. The leading countries in 2020, were Spain, France, China, and Italy, respectively with 13.1%, 10.9%, 10.7%, 9.8% of vineyard surface area (**Figure 2**) [4].

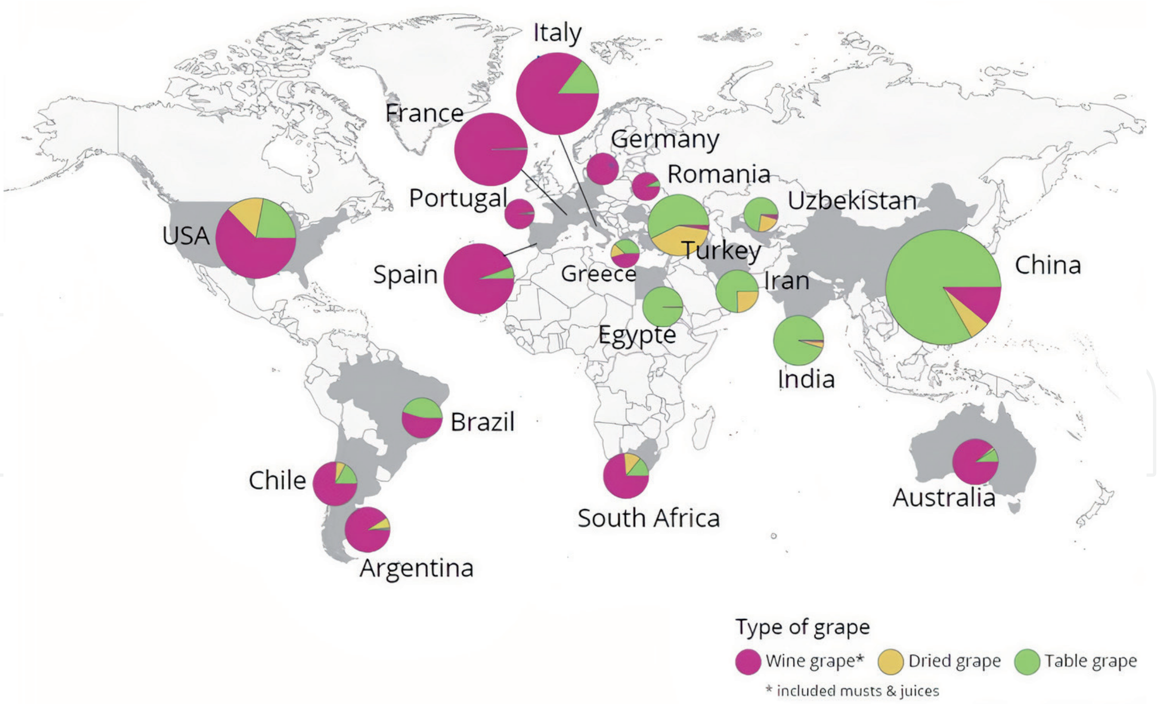

Figure 1.
Major producer countries by type of grape in 2018 [3].

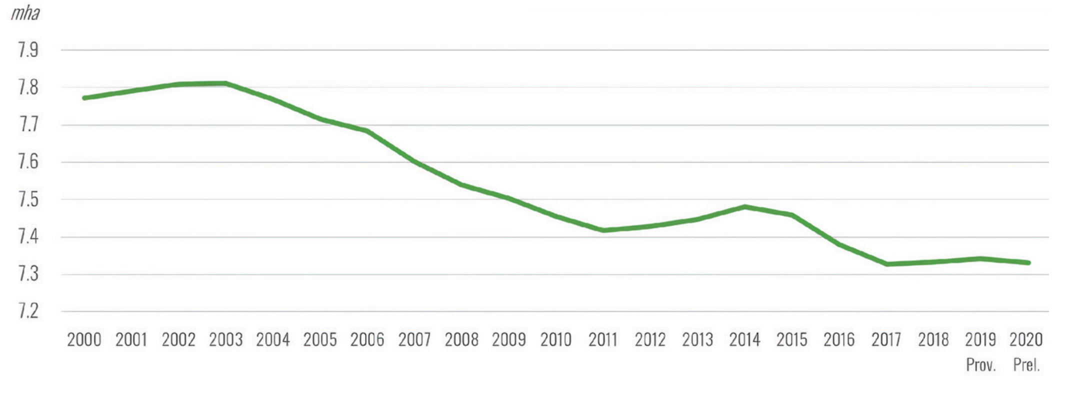

Figure 2.
Evolution of the world vineyard surface area from 2000 to 2020 (in million hectares) [4].

The world consumption of table grapes has increased in recent decades, and there has been an increase in consumer demand for high quality table grapes [5]. According to the *International Organization of Vine and Wine* (OIV) in the beginning of this century, a continuous growth of areas under table grape production was observed until 2017. Between 2007 and 2009 there was a notable growth trend in the production of grapes for fresh consumption, of about 10% (**Figure 3**) [5].

A more detailed analysis of the world table grape production, considering the 2018/2014 ratio, shows an overall value of 2% and allows us to verify that Latin American countries like Peru and Mexico show an important production increase (respectively 0.8% and 0.5%) and Uzbekistan, USA, Brazil, South Africa, Greece, Spain, and Australia show more modest increments between 0.1 and 0.3%. In contrast, Turkey and India show even slight decreases in production [4]. In 2019, Europe produced 1.7 million tons of table grapes for fresh consumption, and ten years ago the production was more than 2.0 million tons (https://www.cbi.eu/market-information/fresh-fruit-vegetables/table-grapes/market-potential).

In the year 2018, China was outstanding as the world's leading table grape producer, producing 9.5 million tons of grapes. The second ones were Turkey and India producing 1.9 million tons each, as it can be appreciated a much lower value.

Figure 3.
World table grapes production from 2000 to 2018 in million tons [3].

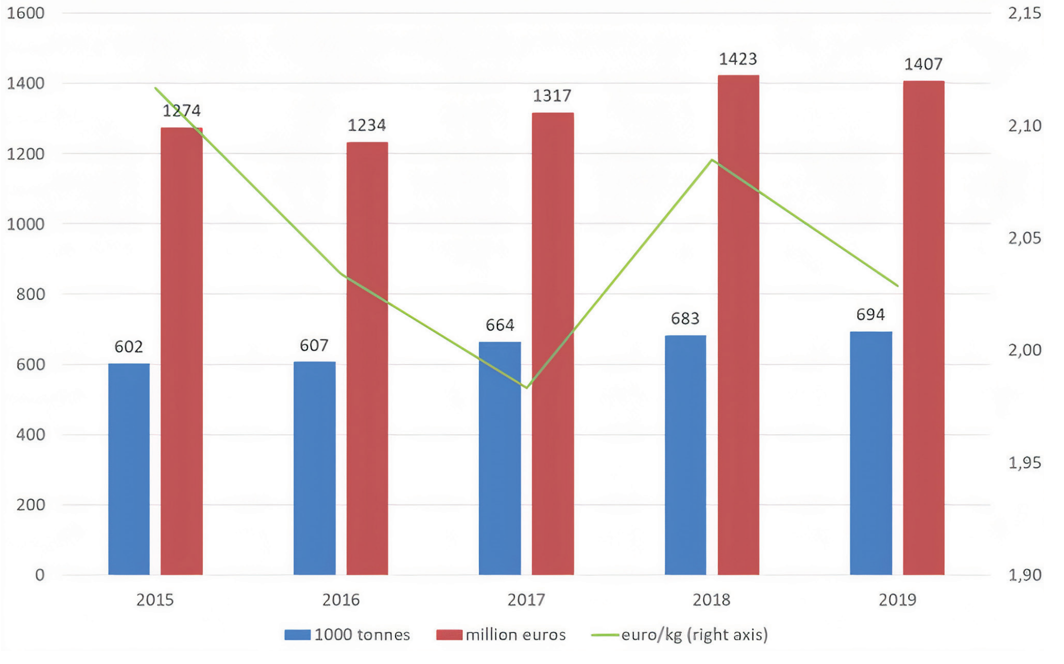

Figure 4.
European imports of table grapes from non-European suppliers (https://www.cbi.eu/market-information/fresh-fruit-vegetables/table-grapes/market-potential).

Another important observation is the increasing exportation of fresh grapes from Chile, Peru, and Turkey, developing countries and new producers. Chilean season starts in December until April, and the USA, China, Netherlands, UK, Korea are main markets for Chilean grapes due to the cycle opposite to that of the Northern Hemisphere.

The import volume of table grapes from non-European suppliers has gradually increased from 602,000 to 694,000 tonnes between 2015 and 2019, corresponding to a value of 1.4 billion Euros in 2019 (**Figure 4**).

The main grape producing countries worldwide are Italy, France, USA, Spain, and China. The more non-European significant grape exporters in the international market were Chile, and USA and in Europe, Italy. On the other side, in 2018, only three countries in Europe imported 25% of the grapes traded globally, namely United Kingdom, Germany, and Netherlands.

The existence of market strategies can be perceived as the introduction of new varieties to different products, a goal to be reached by producers, mainly important producers and companies that are gaining prominence in the international market. Big grape companies are anticipating consumer preferences of seedless grapes and sustainable packaging, for large markets, such as the United Kingdom and Germany.

The crisis caused by the Covid-19 pandemics, turned 2020 into an abnormal year, regarding international trade, and dramatically decreased the demand for table grapes in the supermarkets, for example in Germany and in the UK. This crisis serves to test the resilience of the sector and to be expecting new opportunities in the value chain [6].

The *International Organization of Vine and Wine* is committed to achieve excellence towards environmental sustainability objectives on socio-economic and socio-cultural aspects, in support of the United Nations (UN) 2030 Sustainable Development Goals (SDGs) [4]. In their Strategic Plan 2020–2024, the *International Organization of Vine and Wine*, among the various proposed axes, highlighted the first three:

Axis I - Promote environmentally friendly viticulture, facing climate change through mitigation and adaptation activities.

Axis II - Promote economic activity in accordance with the principles of sustainable development and growth and globalization of markets.

Axis III - Contribute to social development through vitiviniculture.

In the 2020/2021 season, the global production of table grapes is estimated to be maintained at 25.7 million tons, although production in key productive regions, such as Chile, Europe, and the United States substantially decreased, mainly due to the increased production in China [7].

2. Grapevine: family, genus, species, and varieties

Grapevine is a hardy perennial plant, which belongs to the family *Vitaceae*. The plant is a climber with an herbaceous or twining stem, sometimes with tuberous stems, characterized by tendrils and inflorescences opposite the leaves [8, 9]. It bears fruit in clusters, and the fruit, grapes, is botanically called a berry that results from the development of the ovary of the flower [10].

The genus *Vitis* is the most representative of this family and the most interesting for the vine industry. It has over 80 identified species and is composed of two subgenera, *Muscadinia* (2n = 40 chromosomes) and *Euvitis* (2n = 38 chromosomes) [8, 10, 11]. The subgenus *Muscadinia* consists of three species, including *M. rotundifolia*, and is known by resistance to cryptogamic diseases.

The subgenus *Euvitis*, which is divided into three groups: (a) East Asia group consists of about 55 species and shows minor interest in present viticulture; (b) American group consisting of more than 20 species, including *V. labrusca*, *V. riparia* and *V. rupestris*, and shows high interest in use as a rootstock due to resistance to phylloxera; (c) Eurasian group composed of the species *Vitis vinifera* L., the most representative and planted worldwide. It consists of two sub-species: *sylvestris*, which corresponds to the wild form of the vine, and *vinifera*, the cultivated form [8, 11]. According to Creasy and Creasy [8], many of the non-*V. vinifera* species have been vitally important to the commercial development of *V. vinifera* cultivars, in finding a solution to the problem of phylloxera and other soil-related pests and conditions.

Nowadays, the genus *Vitis* presents a large genetic diversity with several thousands of varieties. However, there is a high number of synonyms (different names for the same cultivar) and homonyms (identical name for different cultivars) to be considered. Also, the number of varieties in the world is estimated at 6,000 for the *V. vinifera* species on its own [11]. Additional information on the origin, main use and pedigree of cultivars is available from the *Vitis International Variety Catalog* [12], which allows the rapid and easy comparison between molecular fingerprints.

The existing grape varieties have different features, regarding shape and size of the berry and bunch, berry tonality, organoleptic quality, productivity, among others, which give them aptitude for different uses.

Grapes can be considered for different uses according to their characteristics: (a) wine production and fermented grape products using varieties with higher acidity and moderate sugar content, (b) table grapes for fresh consumption, using varieties with low acidity, low in sugar and that meet specific standards of size, color and shape and (c) raisins, suitable varieties being seedless, with low acidity and rich in sugars [13].

According to recent data presented in the *Vitis* International Variety Catalog-VIVC [12], 53.98% of grape cultivars are used for wine production, 30.57% for table grapes (fresh consumption), 7.42% with dual suitability (wine and fresh consumption), 7.06% for rootstocks and less than 1%, more precisely 0.98% for raisins.

In table grape cultivars, berry size, firmness, sweetness, and color are important characteristics [14]. Berry size and yield are desirable in table grape vineyards, for which full irrigation is recommended [15].

However, some trials conducted by Shahidian and colleagues [16], in a vineyard of 'Crimson', with different irrigation sub-treatments with stress periods, showed significant decrease in mean berry weight, and thus in marketable fruit and also reduction in total soluble solids and an increase titratable acidity (TA), so the consequences of this stress period were a reduction in the maturity index and a delay in the maturity. The use of sap flow ratio between well irrigated reference vines and vines under reduced irrigation can potentially contribute to water savings, in order to find the level of irrigation reduction at non-critical stages of vine growth, triggering irrigation events only at a previously defined critical threshold.

The quality parameters of table grapes differ from wine berries quality parameters, and therefore irrigation practices to optimize berry quality can be quite different [17].

In wine vineyards, full irrigation is not recommended because it increases the size of the berries, which produces a decrease in the proportion of pulp in the skin, which does not benefit the quality of the wine.

Not be forgotten the use of rootstocks in grape plantation, that has become a common practice among grape growers around the world, mainly because rootstocks allow the culture to be conducted under unfavorable soil conditions, such as the presence of nematodes, diseases and pests, high salinity, among others [18, 19]. Around the world, most vineyards are grafted onto commercial hybrid rootstocks from *Vitis berlandieri*, *V. riparia*, or *V. rupestris,* which were developed at the beginning of the 20th century to control *Phylloxera* devastated European vineyards from American *Vitis* spp. [8]. The role of rootstocks in the maintenance of the crop and in the final product obtained has been studied given its relevance, particularly in aspects related to the symbiont's use of soil nutrients [20].

3. Description of the most important commercial varieties

In the last decades, the cultivation of seedless table grape cultivars has increased considerably, because consumers in many countries highly appreciate these new varieties, seedless, with firm and sweet berries [21]. However, those who think that these seedless table grapes are new are mistaken, because as early as the 19th century, William Thompson in California achieved the first significant crop, 50 pounds of seedless grapes. This breeding work has relied on varieties from Turkey and local rootstocks.

The production of seedless, i.e., apyrenic, table grape varieties has been of increasing interest, mainly because the demand in recent decades has grown, since this type of fruit is more convenient to consume [21, 22]. In addition, the selling price of these varieties is usually higher than that of seeded grapes. So, many of the new table grape varieties that have recently come onto the market are apyrenic, and more appreciated and sought after by consumers.

In the case of seedless grapes, it is possible to distinguish two mechanisms of seedlessness depending on the time when development was disrupted: (a) parthenocarpy (observed in Corinth cultivars), which occurs when the ovary is able to develop without fertilization of the ovum; (b) stenospermocarpy (observed in Thompson cultivars), when pollination and fertilization trigger ovary development, but embryo/ovule abortion occurs 2 to 4 weeks after fertilization, and partially developed seeds or traces of seed are visible in the grape [23–25]. In seeded grapes, the transition from flower to fruit requires pollination and fertilization of the ovary for seed formation [23].

According to Costenaro-da-Silva et al. [26] and Varoquaux et al. [25] the parthenocarpy mechanism leads to the development of very small seedless and spherical berries that are usually considered for raisin production, while stenospermocarpy leads to the development of berries with dimensions compatible with commercial requirements for fresh consumption.

According to Picarella and Mazzucato [24] the term parthenocarpy is used in the broad sense to indicate both forms of apyrenia.

However, to obtain a bunch of grapes with a considerable number of well-developed berries, it is necessary to apply particular and complex hormonal treatments. Gibberellic acid is used to thin the bunch berries, elongate the bunch, increase berry size, and reduce seed traces. The concentration of the initial spray of gibberellic acid depends on the cultivar [25].

Seedlessness can also be induced by applying hormones to young inflorescences [24].

The shelf-life of seedless fruits is expected to be longer than seeded fruits, since seeds produce hormones that activate senescence [25].

3.1 Seeded varieties

3.1.1 'Red globe'

The bunches are pyramid-shaped, conical, with wings, semicircular. They can reach exceptionally large dimensions and weight. Berries are seeded large and spherical (9–10 g), consistent, the skin can be easily peeled, with a physical resistance worth mentioning that allow easy management and contribute to a long shelf-life. 'Red Globe' grapes are very sweet with a high soluble solids content (SSC) (19°Brix) and an SSC/TA ratio of 49, which makes them highly appreciated by consumers [27]. They also have a high resistance to rupture in compression, which makes them particularly interesting for postharvest handling and transport [27]. It is an early-budding variety with a long and late maturity period and a long shelf-life.

This variety is the second most cultivated variety for table grapes, covers 159,000 hectares worldwide, and 91% of the area under this variety is in China. 'Red Globe' yields between 8 and 30 tons per hectare [11].

3.1.2 'Cardinal'

'Cardinal' berries are large, spherical with a bright green color and a crisp flesh. They present a slight muscat flavor when fully ripe. This variety was introduced in Europe after the Second World War, and it is very important in the Mediterranean region. Preliminary results obtained with 'Cardinal' grapes grown in the south of Portugal have 17.5°Brix, an acidity of 0.43 g/100 g^{-1} fresh weight, and an SSC/TA ratio of 45 [27].

3.1.3 'Italy'

The berries are large, oval, with a crunchy texture, juicy, sweet, and present a very yellow color. The bunches are medium-sized and well filled out. Long harvest period until the end of the season.

3.1.4 'Palieri'

The bunches are long, medium full and have an average weight of 600 g. The berries are large (17–20 mm) and oval, with a medium-thick, firm skin covered with pruin, and the pulp is crunchy, resistant, juicy, and medium sweet (14°-16°Brix). Preliminary results for 'Palieri' grapes from the south of Portugal have 15°Brix, an acidity of 0.20 g/100 g^{-1} fresh weight, and an SSC/TA ratio of 40 [27]. 'Palieri' grapes are resistant to handling and transport due to high coefficients of apparent elasticity and firmness of the flesh. Moreover, berries are characterized by their high resistance to compression and a low resistance to rupture [27].

3.1.5 'Dona Maria'

'Dona Maria' is a Portuguese variety obtained in the 1950's in the *National Agricultural Station* in Oeiras, Portugal, and quickly spread throughout the country. It is a cross of 'Moscatel de Setubal' and 'Rosaky', their brunches are large or very large, cylindrical, rarely winged. The berries are very large, elliptical in shape, with a yellowish green color when ripe [28]. The skin is resistant, covered with a thick layer of pruin, and the pulp firm and succulent. It is much appreciated for its floral flavor, and very sweet and large berries. The bunch ripens in August and at the first fortnight of September coinciding with many other varieties [28]. Nevertheless, 'Dona Maria' grapes have a great commercial interest in Portugal, due to its light muscatel flavor and sweetness. Moreover, it is practically only sold in local markets. Berries are resistant to transport and keep their fresh appearance for a long period, if cold storage is done correctly, otherwise the berries of yellowish-green color turn brown [28]. The worst defect of 'Dona Maria' is the fact that the berries detach easily from the pedicels in an advanced period of maturation. If this problem is fixed, considering their exquisite flavor and long shelf-life, it could be considered a variety with potential for a wider market.

3.2 Seedless varieties

The cultivation and consumption of seedless table grape cultivars has increased considerably in recent years, by demand of the consumer who highly appreciates the absence of seeds and is willing to pay more for these sweet, firm and seedless grapes [17]. In fact, one of the objectives of the current breeding programs is to obtain varieties with good characteristics and mandatorily seedless [23]. 'Thompson Seedless' is the main source of seedlessness for breeding programs around the world, while also being an important commercial seedless variety for consumption [26].

According to FAO and OIV [29], the criteria to select the new varieties, among other, are: the presence or absence of seeds, shape, color, skin thickness, maturity period, resistance against diseases and pests, capacity to be transported without damage and shelf-life.

Although it seems impossible to list the current commercialized varieties of table grapes, a summary description of those considered to be the most significant, taking into account the following criteria: the varieties with commercial/economic importance, worldwide; the varieties that are very innovative and those that, in our opinion, will be prominent in the future.

According to Fortes and Pais [30], the traditional varieties of *Vitis vinifera* table grapes are: 'Alphonse Lavallée', 'Bastardo Ruzo', 'Dominga', 'Moscatel Negro', 'Muscat of Alexandria', 'Ribier', 'Thompson Seedless'/'Sultanina', 'Tinta Pais'. The modern varieties are 'Autumn Royal', 'BRS Morena', 'Cardinal', 'Crimson Seedless', 'Flame Seedless', 'Guibao', 'Italia', 'Michele Palieri', 'Moscatel Italica', 'Muscadoule', 'Muscat Hamburg', 'Napoleon', 'Otilia', 'Perlon', 'Red Globe', 'Superior Seedless' [30]. Moreover, some table grape varieties resulting from traditional and modern interspecific crossing or other species of *Vitis* have been described, namely: 'Alachua', 'BRS Clara', 'Campbell Early', 'Canadice', 'Delaware', 'Eudora', 'Flouxa', 'Honey Seedless', 'Janet', 'Kyoho', 'Nativa', 'Niagara', 'Ruby Seedless', 'Southland', 'Tamnara', 'Tano Red', 'Concord' and 'Muscat Bailey A' [30].

Recently, a group of researchers from the *Universidade de Évora-MED*, Portugal, in collaboration with a company from the nearby region, proceeded to characterize some apyrenic varieties ('Timco', 'Melody', 'Scarlota' (Sugra19), 'Alisson', 'Melissa' and 'Autumn Royal') produced under the specific climatic and agronomic conditions of a producer company located in Alentejo, South of Portugal (38°05′22.2"N 8°04′51.1"W). The obtained results are generally in agreement with those published worldwide, although with increased soluble solids content (SSC) values. Timco', 'Scarlota' and 'Alisson' table grapes had the heavier berries. 'Melody', 'Melissa' and 'Autumn Royal' were lighter ($p < 0.05$). Although 'Melissa' had the lightest berries, their caliber was higher than most. 'Alisson' has the smallest caliber berries. 'Melissa' had the lower skin firmness of all the varieties studied. There are no statistically significant differences in SCC and their values were all very high. 'Autumn Royal' had the lower acidity of all varieties studied while 'Scarlota' had the highest ($p < 0.05$). Total phenolic content was higher in 'Autumn Royal' and lower on 'Timco' ($p < 0.05$). 'Autumn Royal' showed the higher capacity of scavenging free radicals ($p < 0.05$). Considering all the results presented and the current interests of consumers, 'Autumn Royal' can be pointed out as a very interesting variety from the organoleptic and nutritional point of view. To perform shelf-life tests with this variety produced in this edaphoclimatic conditions is necessary to define an adequate marketing strategy [31].

3.2.1 'Sultanina' or 'Thompson seedless'

'Sultanina' is the first apyrenic or seedless variety cultivated in the world. The synonyms for 'Sultanina' are numerous: 'Kishmish' in Afghanistan, 'Thompson Seedless', 'Sultana', or 'White Sultana', 'Kišmiš', among others [11]. It is an ancient grape variety, originating from Afghanistan. This variety has a multiple purpose use, for drying to produce raisins, for vinification to produce wine especially in Turkey and the USA, distilled to make a spirit beverage (Raki, a typical Turkish beverage obtained by distilling fresh or dried grapes, flavored with aniseed and with an alcohol content of 45%) and also for fresh consumption [11, 32]. 'Sultanina' grapes are highly valued by customers as table grapes due to their organoleptic quality characteristics, mainly sweetness, sharpness, firmness, and light green brilliant color. The berries are seedless, elliptical, of small to medium size, 16–22 mm, and cylindrical in shape, yellowish green. Their flavor is said to be sharp, sweet (17°-19°Brix), juicy and the pulp crisp and consistent. The bunches are large, cylindrical, or conical and compact, with a very variable weight depending on cultivation practices, between 350 g and 700 g. Their small caliber can be improved trough applications of gibberellic acid. Maturation is somewhat late.

According to OIV [11], this variety is the leading variety of table and raisin grapes in the world, with about 273,000 hectares, however, the OIV estimates a decrease of vineyards. It is particularly cultivated in Middle Eastern countries and Central Asia. As extreme production values we can refer to 80 tons/hectare in South Africa [11]. This is one of the most economically important fruit crops worldwide [33, 34].

3.2.2 'Kyoho'

'Kyoho' or 'Kioho' is one of the obtained varieties in Japan before the Second World War, resulting of a cross between tetraploid cultivars of *V. vinifera* ('Ishiharawase') and *V. labrusca* ('Centennial'), very common in Japan. 'Kyoho' was first produced by a breeder named Y. Ohinoue in 1945 with the aim of making a cultivar with large berries due to its tetraploid nature. So, 'Kyoho' purple berries are large (12–14 g), easily peeled skin, characterized by edible flesh, sweetness (18–20°Brix) and a strong but pleasant foxy taste[1]. They are not or not very prone to bursting, but they detach easily from the bunches when fully ripe and have a short shelf-life. 'Kyoho' is generally a seeded grape but can produce apyrenic berries, which are obtained with several applications of gibberellic acid. The 'Kyoho' yield ranges from 12 to 15 tons per hectare [11].

'Kyoho' cultivation area reached 365,000 hectares in 2015, being the most widely grown grape variety in the world. In China more than 90% of the table grape area is occupied with this variety, in Japan, is the most produced one, and 'Kyoho' grapes are very appreciate in South Korea, China and Thailand. The Asiatic consumers appreciate the big caliber and the soft pulp.

3.2.3 'Crimson'

'Crimson Seedless' is a late apyrenic table grape variety. It is one of the most produced table grape cultivars in the world. It results from five generations of hybridizations at the United States Department of Agriculture (USDA) Horticultural Field Station in Fresno (California), and this breeding program started in 1926 [35]. The last cross was between the *Vitis vinifera* cultivar 'Emperor' and the USDA selection 'C33–199', resulting in 'Crimson Seedless' (previously known as 'C102–26' from the USDA selection) [36]. This variety is widely grown in the United States of America, precisely in the state of California, and in Europe, for example in Portugal. 'Crimson' grapes are highly valued by European consumers, who greatly appreciate their firm and crunchy texture, and their taste, which they classify as excellent, for its sweetness [17].

The berries contain inside two aborted seeds that are practically undetectable by consumers. The pulp is light yellow, translucent, fleshy, and firm. Regarding epidermis, it is thick, offers medium resistance and well adhered to the pulp [35]. 'Crimson' grapes present a medium degree of acidity, and the index of ripeness, SSC/TA ratio, varying between 35 and 40 [37]. 'Crimson' presents heterogeneously colored berries and bunches, which depreciates its external evaluation. So, to avoid this obstacle the bunches must be exposed to adequate sunlight during ripening, for this it is common to thin out the shoots and remove the basal leaves that surround the bunches increasing the sun incidence on the bunches [38].

[1] The origin of the term "foxy" is unknown. "Foxiness" refers to a unique wild grape aroma, a combination of an earthy aroma and a sweet muskiness. It is very common in *Vitis labrusca* 'Concord' American grapes. Methyl anthranilate (MANT) is responsible for this aroma, which is also found in fragrant flowers, like jasmine.

Because it is a variety with the characteristics already described and late harvesting, it becomes desirable to increase the availability of these grapes in the market for a longer period, in order to sell them during a time of low supply, when there are higher prices, which could be extremely important for producers [39].

3.2.4 'Autumn royal'

'Autumn Royal' developed by the University of California in Fresno, USA, is a seedless variety that presents large berries, which confers a high commercial value to these grapes. A recent seedless grape variety with large, conical bunches (400-600 g) and elongated, 17–22 mm, dark purple-black thin skin and crunchy skin, translucent white yellow-green and firm flesh. The thin skin hides a firm texture and a crunchy flesh with a neutral flavor and medium sweetness (14°-19°Brix). Generally, these grapes are seedless, however they can develop seed beginnings not detected by consumers.

'Autumn Royal' is a late-season grape adequate to extend the season. Ripening in the middle of summer, Spanish producers harvested this variety from mid-August to mid-September [40].

This variety is susceptible to berry cracking, and this problem has been the subject of numerous studies [41, 42]. Another negative aspect is the weak attachment of the berries to the rachis, for what it should be recommended to handle the bunches very carefully during harvest and postharvest [43].

4. Grapes and ripeness

The grapes are clustered into berries, and each cluster is made up of two distinct parts: the stalk (the woody part) and the berries (the fleshy, edible part). The stalk is composed of a main axis, the rachis (longest branch) that is attached to the peduncle, and shorter branches, the pedicels, which support the berries and provide them with water and mineral salts [44, 45].

The berry, in which the edible part corresponds to the pericarp, is the complex of tissues that surround the seeds, being constituted by three layers [10, 44, 45]:

i. The exocarp (skin) is the external part of the berry, consisting of a heterogeneous and elastic membrane that distends with the development of the berry. The constituent cells of this layer have an active metabolism, presenting a regulatory function, namely of transpiration, of other tissues of the pericarp. The compounds responsible for the color, flavor and aroma are accumulate in the tissues of this layer.

ii. The mesocarp (flesh or pulp) is composed of large, thin-walled, polygonal-shaped cells, which are apparently somewhat disorganized. This layer accumulates high amounts of organic acids and sugars in the vacuoles.

iii. The endocarp is the tissue surrounding the seeds, with more organized cells, but difficult to distinguish from the mesocarp.

4.1 Fruit growth, development, and ripeness

The process of berry development and growth has been the subject of numerous studies, it seems to be consensual that it is characterized by a double sigmoid curve, divided into three distinct stages that report to periods in which specific changes occur in berry development [44, 46, 47]:

i. **Stage I - Berry formation**

This initial phase is characterized by a rapid period of berry growth, which is due to both cell division and an increase in cell volume [43, 45]. The berry, green and firm, behaves like any other green organ of the vine, i.e., it performs photosynthesis and respiration functions [48]. Chlorophyll is the predominant pigment during this phase [47]. In this period the respiration rate is high and there is accumulation of organic acids, such as malic acid and tartaric acid, but the sugar content is reduced, since sugars are consumed during cell multiplication [43]. Cell division decreases and the number of cells becomes definitive, and the final size and shape of the berries is determined [10].

ii. **Stage II - Stationary lag stage**

This period is characterized by a decrease in the rapid growth rate of the berry and the concentration of organic acids reaches its highest level [45]. The berries remain firm, but photosynthesis, respiration rate and chlorophyll concentration decrease [43]. The determination of the maturity phase is accomplished by the duration of a phase of near stability, referred to as the lag phase [10]. The transition between phases II and III is known as *Véraison*, and described as the change in berry color in red cultivars [44].

iii. **Stage III - Berry ripening**

This final stage is characterized by a decrease in the growth of the berry, due to the cessation of cell multiplication, and the increase in volume caused exclusively by the enlargement of its cells. The ripening of the berry begins, and the loss of firmness is marked [45]. The loss of chlorophyll and the increase in the level of abscisic acid, which has an influence on the accumulation of polyphenols, leads to the white cultivars acquiring a translucent yellow and the red ones a light and later dark red color [43]. The supply of water, minerals, cations and sugars is carried by the phloem, since the xylem vessels are blocked from the moment when the berry reaches 6 to 7°Brix [47]. Sugar content increases, while TA decreases [43].

4.2 Physicochemical changes

Water is one of the main constituents of grape berries, and significant amounts are required for their full growth and development [43]. At maturity, grape berries have a water content of around 75–80% of their fresh weight [49].

Throughout berry development, water losses occur mainly due to transpiration, and this intensity depends on climatic conditions and changes during berry development [49]. Most of the water required by the fruit is supplied by the xylem until *Véraison*, but after this period the xylem vessels present in the berry are blocked and water transport is carried by the phloem, the main supplier of water to the fruit [44, 49].

Sugars result from the photosynthesis process carried out in the green organs of the vine, migrating to the various parts of the plant in the form of sucrose [49]. Until the beginning of the *Véraison*, sugars are consumed in cell growth, but also by migrating to the fruit for the growth and maturation of the seeds [44]. Sugars are the basis for several compounds, such as organic acids and amino acids, synthesized and found in the fruit [43].

Sucrose, a sugar predominantly transported in the phloem, is formed by the union of a glucose and a fructose molecule. When the sucrose is in the berry it is hydrolyzed, forming again the referred hexoses (fructose and glucose), existing in the pulp [43, 44].

At harvest, the amounts of glucose and fructose are approximately identical, varying between 8 and 12% of the fresh weight of the fruits, and after maturity there is a tendency for fructose to predominate [43]. Sucrose and other sugars are present in the fruit, but in very small amounts [43].

The main organic acids present in grape berries are tartaric, malic and citric acids, with the first two representing more than 90% of the total acids in the berry [43–45]. Tartaric acid is a secondary product of sugar metabolism and its content increases during herbaceous growth due to intense cell multiplication. Regarding malic acid, it is an intermediate of sugar metabolism and during herbaceous growth the sugar produced gives rise to this acid that is stored in the vacuoles of the pulp cells [45]. Tartaric acid is biosynthesized before *Véraison*, so the amount per berry remains stable, while malic acid is biosynthesized before *Véraison*, but also during ripening, and is degraded through respiration, which consequently leads to a decrease in its amount per berry [46, 49].

During *Véraison* and the ripening period, the berry volume increases and the membrane tension of the vacuoles in the pulp cells starts to decrease, which leads to the degradation of malic acid [43, 46].

Phenolic compounds, also called polyphenols, are organic compounds that result from the secondary metabolism of plants and are biosynthesized through the shikimic acid cycle. They are defined as substances that have an aromatic ring consisting of six carbon atoms with one or more hydroxyl groups or derivatives of this basic structure [49]. The phenolic content of plant-based food depends on intrinsic factors such as genus, species and variety and extrinsic factors such as agronomic and environmental conditions, ripening process, and storage conditions. Phenolic compounds are present in the berry since its formation, resulting from the catabolism of sugars [44]. They are synthesized in the berry, with different amounts, proportion and types in the skin, pulp, and seeds, and can vary significantly among cultivars [44, 50]. Regarding the total phenolic compounds present in the berry, it is known that in the skin the total extractable phenolic compounds are between 28 and 35%, the pulp presents values below 10% and the seeds between 60 and 70% [50]. Grape is one of the major sources of phenolic compounds in the human diet, the main classes of phenolics compounds in grapes are flavan-3-ols, tannins, anthocyanins, flavonols, hydroxycinnamic acids, hydroxybenzoic acids and stilbenes [49]. These compounds are of great interest since they have high nutritional value and protective function against diseases caused by oxidative damage, such as heart disease, stroke and cancer [49]. White grapes, when compared to red grapes, have lower total phenolics contents, partially because they do not synthesize anthocyanins in significant amounts [44]. These compounds can act as antioxidants in several ways, namely by scavenging free radicals, scavenging oxygen radicals and as chelators of metal ions [50]. Moreover, they play an important role in grape quality, since they inhibit lipid oxidation and participate in the processes responsible for color, astringency and aroma, inhibit lipid oxidation and fungal proliferation [50].

Mineral elements naturally originate in the soil and their accumulation in grape berries is accomplished via the xylem, except for potassium which accumulates via phloem [51]. These elements constitute between 0.2 and 0.6% of the fresh weight of the berry [52]. During berry growth, the accumulation of large amounts of nitrogen, calcium, phosphorus, and magnesium occurs, with the main mineral being potassium [49]. The accumulation of nitrogen and potassium is carried out before and after *Véraison*, while the accumulation of calcium, phosphorus and magnesium is preferentially carried out after *Véraison* [46]. The distribution of mineral elements between the epidermis and pulp and their accumulation in the berry varies depending on factors such as variety, climatic conditions, and water availability [46]. The accelerated berry transpiration could be associated with higher fruit mineral nutrient content [49]. Mineral elements are highly important for human nutrition because they are not synthesized by our body, which has led to an increasing interest in studies on the constitution of fruits and vegetables in this type of elements.

There are different definitions for food texture, and it can be evaluated through sensory analysis and/or instrumental methods, which are related to the evaluation of food structure and the determination of its chemical composition. Textural attributes vary during the pre- and postharvest period, being affected by ripening stage, plant nutrition, water stress, storage temperature and relative humidity [53].

The fruit texture is dependent on the biomolecules involved in the cellular structure of the cell walls being the changes mostly attributed to changes in the composition and structure of cell wall polysaccharides [54].

With the initiating changes in fruit texture, there are modifications in the chemistry of the middle lamella and primary cell wall components (pectins, celluloses, and hemicelluloses) that accelerate the loss of fruit firmness [55, 56]. Studies conducted during storage period of grapes suggest that a reduction of cell wall pectins and hemicelluloses occurs, since during fruit ripening these undergo solubilization and depolymerization, which contributes to cell wall disintegration [56, 57]. Moreover, softening has also been associated with the flow of carbohydrates and osmotically active nutrients to the fruit due to competition for the accumulated reserves and the phytohormonal-caused differential movement of solutes [38].

According to Ejsmentewicz et al. [56], homogalacturonan (HG) is proposed as one of the main components of the cell wall, involved in the texture changes of fruits.

The importance of texture evaluation is due to the knowledge of these textural changes during ripening, and storage and with the differences found among varieties, being a quality attribute valued by consumers in table grapes.

The rheological behavior of foods is related to the deformation, disintegration, and flow when a force is applied, and the response can be evaluated as a function of force, time, and deformation. According to Abbott [58], fruits have a viscoelastic behavior when subjected to a load, so the force, time and deformation (intensity, duration and speed of the load) determine their rheological behavior.

In table grapes, the instrumental determination of the consistency of the berry epidermis and the compactness of the pulp, provides relevant information about the acceptability of the product by the consumer [59]. Grape berry texture is one of the most important quality parameters affecting the consumption of this fruit [56, 58].

According to Rolle et al. [60], from the point of view of consumer texture of table grape berry includes different attributes, mainly hardness (firmness), elasticity, shape, and sensations in the mouth during chewing.

The texture analysis is a rapid, and low-cost analytical technique, that can be applied in viticulture and enology as a routine monitoring tool for the grape quality. Previous studies have indicated that the grape texture is linked to cultivar and growing location, reflecting a terroir influence on grape quality [61, 62], and instrumental texture parameters were used to investigate the effects of vineyard practices [38, 50].

The color of the grape skin or exocarp is classified as green-yellow, pink, red, red-gray, violet-dark red, blue-black and red-black [63]. This attribute can be easily assessed instrumentally in color spaces, the most commonly used being CIELab, in which the color is defined by the coordinates L*, a* and b*.

5. Quality and postharvest

The quality of a product encompasses sensory attributes, nutritional value, chemical constituents, textural properties, functional properties, and defects [58]. Consumers use their five senses - sight (appearance), smell (aroma), taste, touch (texture) and hearing to evaluate the product quality, and integrate all these senses to decide on the acceptability of the product [58].

In the specific case of consumer acceptability and quality evaluation of table grapes different attributes must be considered, which are reached in the third and last stage of berry development, and includes intrinsic (visual, mechanical, chemical, etc) and extrinsic (cultivar, production methods, country of origin, price, etc) attributes [59].

Visual characteristics and physicochemical properties are involved in sensory and quality evaluation of table grapes. The color, size and shape of the berry are the primary characteristics that consumers observe, together with taste, aroma, and texture [59, 64]. Consumers favor freshly picked, moderately dense triangular bunches, with a fresh, green-colored rachis. They also prefer grapes with juicy, firm flesh and few or no seeds [45, 59].

The firmness of grape berries is a quality parameter widely associated with the characteristic of crunchiness, and indicates that they have been recently harvested [54]. Loss of firmness is associated with loss of turgidity and physiological modifications that affect berry structure [54, 56].

The harvest date of table grapes is set by the producer taking into account the following quality parameters: SSC, TA, SSC/TA ratio and color [59].

Table grapes are considered non-climacteric fruits with a relatively low rate of physiological activity that exhibits a gradual decrease in respiration during ripening [65]. The berries exhibit very low ethylene production and low respiratory intensity, while the respiratory intensity of the rachis is 15 times higher than that of the berries [45]. Therefore, the quality of table grapes tends to deteriorate rapidly during postharvest, reducing its shelf-life.

Table grapes are subject to severe postharvest losses during the storage and long-distance transport, being mainly of physiological, mechanical, and microbial infection origin [66]. During postharvest, table grapes are sensitive to rapid moisture loss, which results in rachis drying and browning, water loss, berry shatter, and fungal infections (mainly caused by *Botrytis cinerea* Pers. and *Penicilium* spp.), the most important factors limiting their quality and marketability and causing quantitative and quality losses [40, 59, 66]. This type of disorder often occurs due to improper handling during harvest, and throughout the marketing process. However, this characteristic is very distinct among varieties, in some cases being an obstacle to its commercialization over long distances, as is the case of the 'Dona Maria' Portuguese variety. Temperature and humidity control, as well as improved packaging conditions can reduce the undesirable occurrence of fungi.

It is generally agreed that the most important and destructive postharvest disease in table grapes is gray rot, caused by the fungus *Botrytis cinerea* Pers. [45, 47]. Gray rot can originate from latent infections initiated before harvest, from spores present on the bunch, and from visibly infected berries that have not been eliminated during selection operations [47]. These, which at the beginning have a white coloration, after a few days acquire a grayish coloration, which characterizes the disease (**Figure 5**) [47].

Another disease that occurs during the postharvest period is blue rot caused by fungi of the genus *Penicillium* spp., which although less important than the one mentioned above, also causes damage during the storage period of table grapes (**Figure 6**).

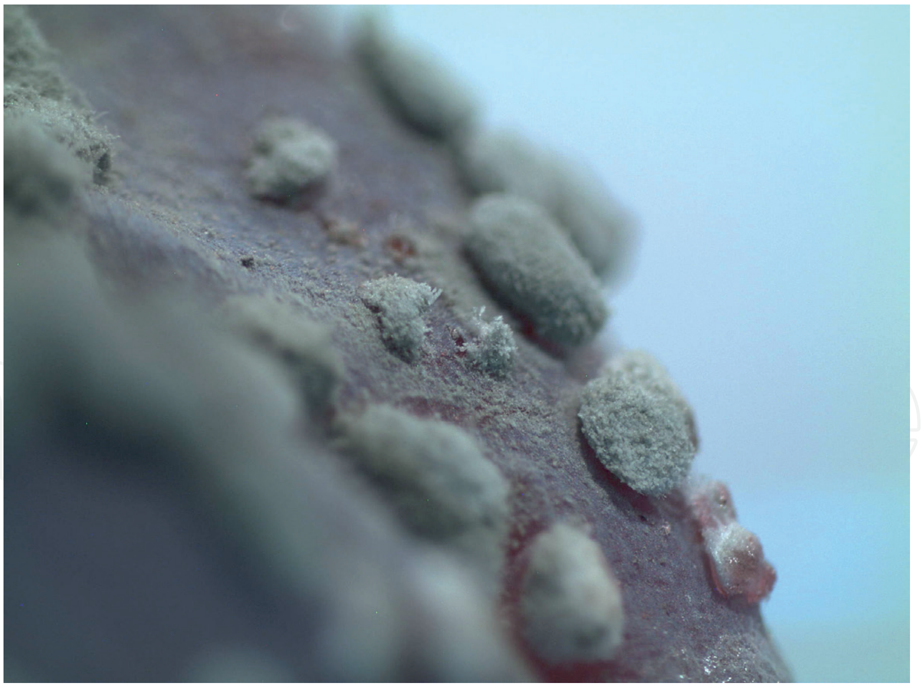

Figure 5.
Magnifying glass observation of Botrytis cinerea on a 'Crimson' table grape berry using an Olympus SZ61 at 350X magnification.

Figure 6.
Magnifying glass observation of Penicillium spp. on a 'Crimson' table grape berry using an Olympus SZ61 at 350X magnification.

The contact of infected fruit with healthy fruit, leads to its contamination, so that through the existence of an inoculum in a berry, it easily spreads throughout the cluster [47]. The infection can be initiated in the vineyard, in the packaging units or during the storage period.

The most commonly applied postharvest techniques are based on the optimization of temperature and control of the relative humidity of surrounding atmosphere, as well as the development of packaging, which limits the decrease in moisture content and protects against physical damage during the entire postharvest period.

Temperatures between −1 and 1°C and 90 to 95% relative humidity are established as assertive conditions for table grapes [45, 47]. Refrigeration, associated with high relative humidity, is one of the most appropriate technologies to extend the shelf-life of fruits, since low temperatures decrease biochemical reactions, microbial activity and minimize moisture loss by reducing transpiration [67].

The commercially recommended method for table grape preservation consists of rapid pre-cooling immediately after harvest followed by sulfur dioxide (SO_2) spraying, keeping the temperature and relative humidity at these values constantly throughout the storage period, which will decrease the losses associated with this period [47]. The use of sodium metabisulfite generators is another of the table grape preservation practices commonly used in the international market, in the form of papers impregnated with the active substance, or bags with the solution or powder formulation, considering the higher the temperature and relative humidity, the faster the gas is generated [47].

Modified atmosphere packaging (MAP), associated with refrigeration, has beneficial effects in preventing weight loss, reducing metabolic activity, decreasing color changes in the berry and rachis, reducing respiration rate, decreasing microbial populations with consequent reduction of fungal incidence over shelf-life [68, 69]. Moreover, several studies have referred the use of MAP in table grapes, with perforated and non-perforated plastic films, based especially on polyethylene and polypropylene [69].

The use of controlled atmospheres (CA) is another technique used to maintain quality attributes and control postharvest losses in table grapes.

In addition to the techniques presented, it is also possible to mention the use of ultraviolet radiation (UV-C) [70], hypobaric and hyperbaric treatments [71] and treatments with gaseous ozone, ozone in water or ozone injection in the cooling chambers [72–74].

Therefore, it remains necessary to develop strategic, residue-free alternatives for postharvest quality control of table grapes that are safe for health and the environment and compatible with commercial practices.

In recent years, there has been a growing interest in the use of innovative and environmentally friendly technologies, such as edible coatings or films and biodegradable films associated with the application of natural compounds, like essential oils, that will both add value to food products and extend their shelf-life [75–77].

6. Nutritional value of table grapes

The nutritional and functional interest of grapes in the human diet makes relevant the knowledge of its chemical composition, which is very complex. Although there are differences in the chemical level for different varieties, agronomic aspects, and locations. The chemical composition of grapes (European type, such as 'Thompson seedless'), red or green, raw, is presented below in a generic way, according to the USDA *FoodData Central* (**Table 1**) [78].

In general, table grapes, like other fruits, have a high-water content, close to 80%, provide carbohydrates, mainly in the form of sugars, and are low in proteins and lipids. It also noteworthy the large quantity and diversity of vitamins, essential amino acids, and minerals, with a high potassium content.

It should also be noted that grapes are rich in different polyphenols (phytochemicals which are antioxidant compounds), which contribute to physiological and biological activity for the food industry such as antioxidant and antimicrobial activities [79, 80].

Resveratrol is a phenolic compound with antioxidant activity, present in berry skin of grapes. Analyses with 'Dona Maria' grapes revealed that this variety has high concentrations of this compound [28].

In recent years, there has been a notable increase in the interest for grape by-products, such as seeds and skins, which have nutritional properties and biological potential with nutritional and pharmaceutical application, such as anticancer, anti-inflammatory, cardiovascular prevention [79, 81, 82].

Components (per 100 g)			
Water	80.54 g	Total dietary fiber	0.90 g
Energy	69.00 Kcal	Sugars	15.48 g
Protein content	0.72 g	• Sucrose	0.15 g
Fat content	0.16 g	• Glucose	7.20 g
Carbohydrates (by difference)	18.10 g	• Fructose	8.13 g
Minerals			
Calcium (Ca)	10.00 mg	Potassium (K)	191.00 mg
Iron (Fe)	0.36 mg	Sodium (Na)	2.00 mg
Magnesium (Mg)	7.00 mg	Zinc (Zn)	0.07 mg
Phosphorus (P)	20.00 mg	Copper (Cu)	0.13 mg
Vitamins			
Vitamin C (total ascorbic acid)	3.200 mg	Folate, total	2.000 µg
Thiamin	0.069 mg	Vitamin B12	0.000 µg
Riboflavin	0.070 mg	Vitamin A	3.000 µg
Niacin	0.188 mg	Vitamin E	0.190 mg
Vitamin B6	0.086 mg	Vitamin D	0.000 µg
Fatty Acids			
Saturated fatty acids (SFA)	0.054 g		
Monounsaturated Fatty Acids (MUFA)	0.007 g		
Polyunsaturated Fatty Acids (PUFA)	0.048 g		

Table 1.
Chemical composition of table grapes. Nutritional information about energy value of the grape per 100 grams of fresh weight for organic constituents; per 100 g of dry weight for minerals [78].

7. Conclusions

Table grape production worldwide has been stable for several years, mainly due to increased production in China. In fact, conventional production areas, such as Europe or the United States, have decreased their production area in recent years. Some players in the international table grape market are gaining relevance, such as South Africa and South American countries.

Traditional table grape varieties, such as 'Red Globe' or 'Cardinal', are still commercially interesting varieties, mainly due to their extended shelf-life. However, consumers prefer seedless varieties, especially for their sweetness, such as 'Crimson' or 'Thomson Seedless'/'Sultanina'. In fact, although research on some of these varieties has been done for quite some time now, they are still a challenge to producers due to their shorter shelf-life, related to reduced viability and browning of the rachis, among other problems.

Innovative preservation postharvest methodologies need to be further developed and tested under field conditions, in a joint, collaborative effort between academia and producers, to extend the shelf-life of the most valued seedless table grape varieties.

Acknowledgements

This work was supported by Portuguese National Funds through FCT - *Fundação para a Ciência e a Tecnologia* under Project UIDB/05183/2020 (MED).

Conflict of interest

The authors declare no conflict of interest.

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