



Article

Antioxidant Capacity and Cardiovascular Benefits of Fruits and Vegetables: A Proposal for Comparative Scales

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Abstract: Fruits and vegetables are sources of natural nutraceuticals. They contain a variety of bioactive compounds such as vitamins, minerals, dietary fibers and other phytochemicals that contribute to their health-promoting properties and disease prevention. A wide variety of fruits and vegetables should be eaten to ensure that an individual's diet includes a combination of phytonutraceuticals and to obtain all their health benefits. This study aimed to compare the antioxidant potential and cardiovascular benefits within a restricted sample of ten fruits and ten vegetables, previously reported as largely consumed in Portugal. With data available from the literature, antioxidant potential scales were established. Additionally, a set of seven criteria, including high antioxidant capacity (FRAP values above 1), presence of n-3 fatty acids, saturated fat, cholesterol, trans fatty acids, fiber and sodium was used to create comparative scales of their potential cardiovascular benefits. The main results showed that the fruits that simultaneously exhibited the highest antioxidant potential values and the highest cardiovascular potential benefit were lemon, grapes, and melon; among vegetables, the top rankings were found to be tomato and onion. These products have been recognized as interesting sources of natural nutraceuticals for the food and pharmaceutical industries. In the future, similar approaches are desirable to translate complex scientific data into practical, simple and user-friendly information for food literacy initiatives, including nutrition education materials, about the relative level of the potential cardiovascular benefits of a wide diversity of food products.

Keywords: fruits and vegetables; nutraceuticals; antioxidant potential; cardiovascular benefits; human health; food literacy



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1. Introduction

Fruits and vegetables are vital to diets worldwide, with certain foods or compounds traditionally believed to help prevent and treat diseases despite ongoing debate about their exact role.

The World Health Organization (WHO) [1] recommends consuming at least 400 g per day of fruits and vegetables to obtain broad health and nutritional benefits, although the vast majority of people do not consume enough fruits and vegetables [2]. In 2017, around 3.9 million deaths worldwide were attributed to diets characterized by insufficient fruit and vegetable consumption. It is estimated that about 14% of deaths from gastrointestinal cancers, 11% of ischemic cardiovascular diseases, and about 9% of strokes are directly related to low intake of fruits and vegetables [3].

The International Year of Fruits and Vegetables was celebrated in 2021 with the main purpose of raising awareness of the nutritional and health benefits of fruits and vegetables

and their contribution to a balanced and healthy diet and lifestyle, as well as reducing losses and waste in their production and marketing [3].

Antioxidants are compounds that inhibit the oxidation of other molecules and protect the body from the damaging effects of reactive oxygen species. These free radicals are generated either by normal cell metabolism or as an effect of toxicological external factors, or even as pharmacological secondary effects. Thus, they are responsible for premature aging and play a role in cardiovascular disease, degenerative diseases, chronic metabolic diseases, and cancer [4].

Antioxidants are a broad group of compounds present in food products, diverse in their chemical characteristics and on their precise effect in metabolic pathways and biological impact on cells and health. They share the association with large health benefits and lower risks of various age-related diseases and chronic non-communicable diseases [5,6].

Plant foods are significantly more important than non-plant foods as sources of antioxidants in human diet, although variations exist in food samples [7]. In fact, antioxidant food tables have been drawn [7,8]. Herbs and spices may be particularly rich in antioxidants [7], but the quantity used each time is very small compared to fruits and vegetables. There is a diversity of nutrients with antioxidant properties, and fruits and vegetables are among the foods with the highest density of antioxidants [9] making these foods especially important in providing for the nutritional needs of humans.

Being the synthesis of antioxidants in plant foods induced by mechanical injury as a defense response for wound healing and repair, cutting damage can induce several fruits and vegetables to produce a large number of phenolic compounds, resulting in an increase of antioxidant activity in fresh-cut fruits and vegetables [10]. Breeding can also contribute to changing the levels of these compounds [11]. But the increase in reactive oxygen species during postharvest storage and distribution of fruits and vegetables may induce a depleted state of antioxidant pools to protect their cells, reducing the bioavailability of antioxidants for human consumption [12]. These conditions reinforce the nutritional recommendations regarding the relative quantity of plant foods in a healthy diet and the preference to consume fresh fruit and vegetables instead of processed foods.

Antioxidants exert both additive and synergistic effects in reducing the risk of chronic diseases, and a combination of foods already rich in antioxidants, such as salads and meals with mixtures of fresh vegetables or fruit ingredients will enhance the synergistic action of the different phytochemicals [13]. Nutraceuticals were described as “food or part of a food that provides health benefits and is used for prevention or treatment of a disease”. The development of specific horticultural models for nutraceutical fruit production could be an interesting opportunity to obtain highly standardized raw material for fresh or derived products. Moreover, research carried out in the field of natural bioactive compounds is increasing our understanding of healthy compounds that are naturally available in food, in particular in fruits [14].

Nowadays, a regular consumption of a vegetable-rich diet is recognized to have utmost importance through: (a) the richness and diverse content of nutrients with a recognized function namely acting as regulatory agents in metabolic pathways; (b) the content of bioactive chemicals, even found in trace amounts in foods, which grant those foods a wide range of therapeutic possibilities and which provide health advantages in addition to basic nutritional value. These phytochemicals provide physiological advantages acting in the prevention or treatment of chronic illnesses [15–17] or improving functional, mental, and physical activities [18].

Lifestyle interventions, including balanced diets and regular physical activity, have been shown to significantly reduce the impact of metabolic disorders. Various nutraceutical agents, such as polyphenols, omega-3 fatty acids and antioxidants, exhibit properties that restore redox balance and temper chronic inflammation. Thus, they are capable of regulating pathways to mitigate oxidative-stress and inflammation-associated metabolic and cardiometabolic disorders [19].

The main objective of this study was to compare the antioxidant potential and cardiovascular benefits inside a restricted sample of ten fruits and ten vegetables, previously reported as largely consumed in Portugal. With data available from literature, antioxidant potential scales were established. Furthermore, a set of seven criteria, including high antioxidant capacity (FRAP values above 1), presence of n-3 fatty acids, saturated fat, cholesterol, trans fatty acids, fiber and sodium was used to create comparative scales about their cardiovascular benefits.

2. Materials and Methods

Sample and Data Collection

This study was conducted following the work carried out by Oliveira et al. (2023) [20]. In that study, the consumption profile of organic fruits and vegetables by the Portuguese population was investigated. In the present study, we selected the 10 most frequently consumed fruits, and the 10 most frequently consumed vegetable products as referenced in that study, which served as the inclusion criteria for the samples. Following this selection, we applied the following methodology: 1st, we conducted a review of bibliographic sources for quantitative data on the antioxidant potential of the fruits and vegetables under analysis; 2nd, data from the literature were selected to allow for comparative analysis; 3rd, average, minimum, and maximum data from the literature were compiled into a table; 4th, criteria were selected and used to determine the scale of the antioxidant potential of fruits and vegetables; and 5th, the calculation of the cardiovascular benefit potential of each product was performed.

Descriptive statistical data analysis was performed in Microsoft® Excel® for Microsoft 365 MSO (version 2301 Build 16.0.16026.20002) 64-bit.

For the calculation of cardiovascular benefit, i.e., the potential each food item may have on the consumer's cardiovascular health, seven criteria were defined to obtain the cardiovascular benefit score (from 0 to 7). The following criteria, adapted from Carvalho & Teixeira (2017) [21], were considered:

- High antioxidant capacity (FRAP values above 1)
- Presence of n-3 fatty acids
- Less than 2% saturated fat per 100 g
- Less than 50 mg of cholesterol per 100 g
- Free of trans fatty acids
- More than 2.5 g of fiber per 100 g
- Less than 200 mg of sodium per 100 g

To access the food content values of the selected fruits and vegetables, for saturated fat, cholesterol, trans fatty acids, fiber and sodium, the Portuguese Food Composition Table, version 6.0—2023, of the National Institute of Health Dr. Ricardo Jorge—Department of Food and Nutrition (INSA, 2023) [22] was consulted as the primary reference source for nutritional information. Additionally, the FoodData Central database of U.S. Department of Agriculture—Agricultural Research Service, was also consulted to access the content of n-3 fatty acids (ARS, 2022) [23,24].

3. Results

3.1. Antioxidant Potential of Fruits and Vegetables

Tables 1 and 2 present the antioxidant potential values of the ten most consumed fruits and vegetables in Portugal, according to Oliveira et al. (2023) [20]. Unfortunately, there are no data available in the literature for all fruits and vegetables produced through organic farming. Therefore, we chose to select studies and their respective data from products obtained through conventional agriculture.

Table 1. Antioxidant potential values of fruits according to literature.

Fruits	Antioxidant Potential (Average Value) $\mu\text{mol}/100\text{ g}$	Antioxidant Potential (Min.–Max.) $\mu\text{mol}/100\text{ g}$	References
Orange <i>Citrus × sinensis</i> L.	1.05	0.83–1.59	[7] [25] [26]
Lemon <i>Citrus limon</i> (L.) Burm. f.	8.27	0.56–14.34	[7] [27] [26]
Strawberry <i>Fragaria × ananassa</i> (Duchesne) L.	2.03	1.59–2.47	[27] [25] [26]
Apple <i>Malus domestica</i> Borkh.	0.40	0.15–1.22	[7] [25] [26]
White grapes Red grapes <i>Vitis vinifera</i> L.	1.08 5.33	0.13–4.78 0.32–16.38	[7] [27] [25] [26]
Pear <i>Pyrus communis</i> L.	0.21	0.02–0.41	[7] [25] [26]
Watermelon <i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai	0.44	0.02–0.86	[7] [27] [25]
Melon <i>Cucumis melo</i> L.	1.34	0.29–3.34	[7] [27] [25]
Banana <i>Musa acuminata</i> L.	0.28	0.08–0.42	[25] [7] [26]
Loquat <i>Eriobotrya japonica</i> (Thunb.) Lindl.	0.53	0.56–0.85	[25] [27]

The following tables aim to identify the average, minimum, and maximum values of total antioxidant potential for fruits and vegetables identified as the ten (10) most consumed in Portugal. Those values were obtained through a literature review of studies using the FRAP method (ferric-reducing ability of plasma) to quantify the antioxidant potential present in foods.

The following results were observed: fruits like lemon, red grapes and strawberries demonstrated the highest average FRAP values, indicating superior antioxidant potential.

All fruits mentioned in Table 1 are currently consumed in Portugal, some of them mostly dependent on seasonal (such as melon and watermelon) or even local production (such as loquat); some with national varieties produced in certified regions (such as orange, apple, pear, banana and grape); but many of them somehow available almost all year around benefiting of world commerce. Beyond direct consumption, traditional and contemporary Portuguese cuisine includes fruits as salads and courses components. Lemon is also broadly used as seasoning for salads, courses and drinks.

Considering the array of vegetables most consumed in Portugal, Table 2 includes products used as large components of several culinary preparations (as in the case of cabbage, potato, pumpkin and zucchini, broadly used in soups); products mostly used in salads (such as lettuce, tomato and onion); products used broadly as course meal components, as salad component, as seasoning for salads and stew base (such as tomato,

carrot and onion); and other products usually used in small amounts in a meal but widely used in Portuguese cuisine (such as garlic). Among vegetables, tomato and onion ranked highest in antioxidant potential.

Table 2. Antioxidant potential values of vegetables according to literature.

Vegetables	Antioxidant Potential (Average Value) $\mu\text{mol}/100\text{ g}$	Antioxidant Potential (Min.–Max.) $\mu\text{mol}/100\text{ g}$	References
Lettuce <i>Lactuca sativa</i> L.	0.95	0.07–2.08	[7] [27] [26]
Tomato <i>Solanum lycopersicum</i> L.	2.41	0.16–5.00	[7] [27] [26]
Potato <i>Solanum tuberosum</i> L.	0.40	0.06–1.44	[7] [27] [26]
Carrot <i>Daucus carota</i> L.	0.83	0.02–1.66	[7] [27] [26]
Onion <i>Allium cepa</i> L.	2.91	0.11–6.86	[7] [27] [26]
Garlic <i>Allium sativum</i> L.	0.60	0.06–2.68	[7] [27] [26]
Zucchini <i>Cucurbita pepo</i> L.	0.84	0.03–1.78	[7] [27]
Cabbages <i>Brassica oleracea</i> L.	0.9	0.02–3.5	[7] [26]
Sweet potato <i>Ipomoea batatas</i> (L.) Lam.	0.16	0.08–0.24	[7]
Pumpkin <i>Cucurbita pepo</i> L.	0.04	0.02–0.05	[7]

In fact, those vegetables are quite significant of the Mediterranean influence in the Portuguese culinary tradition. Food and nutrition education emphasize the consumption of vegetables, and following the Portuguese culinary tradition the average value of antioxidants in tomato and onion may indicate that those products are very important sources in Portuguese cuisine.

From the range of values found for each food, an average value was calculated. Results show that, as a whole, in this selected group of fruits, half of them present a value equal or above 1, while in the selected group of vegetables, only two of them present a value equal or above 1.

3.2. Antioxidant Potential Scale

In order to obtain an antioxidant potential value for each fruit and vegetable that would be easy to apply on food literacy instruments, arbitrary value ranges of antioxidant potential were created (0–0.50, >0.50–1, >1–1.50, >1.50–2, >2–2.50, >2.50–3, and >3), based on the ranges of FRAP method values ($\mu\text{mol}/100\text{ g}$) presented in Table 1 for each fruit and Table 2 for each vegetable. Those intervals were assigned a scale from one (1) to seven (7), respectively. Every interval has an equal range of values in an arithmetic progression. This criterion intends an easy perception of the antioxidant content of each fruit or vegetable and the differences between foods. Table 3 shows the “antioxidant potential” scale for

fruits. Table 4 presents the results for the “antioxidant potential” scale for vegetables. Each fruit or vegetable is assigned to one or more points of the scale according to the diversity of values mentioned in the literature. Although the reason for the range of values for the same fruit or vegetable is not mentioned in the literature found, it is understandable that a multitude of factors (genetic variety within species, biochemical, environmental, crop conditions) may influence that value.

Table 3. Antioxidant potential values of fruits.

FRAP Values μmol/100 g	0–0.50	>0.50–1	>1–1.50	>1.50–2	>2–2.50	>2.50–3	>3
Scale	1	2	3	4	5	6	7
Fruits							
Orange		•	•				
Lemon		•	•	•	•	•	•
Strawberry				•	•		
Apple	•						
Grapes	•	•	•	•	•	•	•
Pear	•						
Watermelon	•						
Melon	•	•	•	•	•	•	•
Banana	•						
Loquat	•	•					

Table 4. Antioxidant potential values of vegetables.

FRAP Values μmol/100 g	0–0.50	>0.50–1	>1–1.50	>1.50–2	>2–2.50	>2.50–3	>3
Scale	1	2	3	4	5	6	7
Vegetables							
Lettuce	•	•	•	•			
Tomato	•	•	•	•	•	•	•
Potato	•						
Carrot	•	•	•	•			
Onion	•	•	•	•	•	•	•
Garlic	•	•	•	•	•	•	
Zucchini	•	•	•	•			
Cabbages	•	•	•	•	•	•	•
Sweet potato	•						
Pumpkin	•						

Considering the scale based on value intervals arranged in an arithmetic progression, and the values found in literature mentioning those ten most consumed fruits in Portugal, Table 3 clearly shows that lemon, grapes and melon are the fruits that may present the higher antioxidant potential among the ten fruits compared. They also present the widest range in content on natural antioxidants, which means their contribution to intake may not be necessarily be the highest. Also, for grapes and melon, seasonality has a strong importance in their consumption.

Tomato, onion and cabbage, followed by garlic, are among the ten most consumed vegetables in Portugal, and figure in those which were ranked with the higher antioxidant potential values among the ten studied vegetables. They also present the widest range in content on natural antioxidants. However, all of them are vegetables highly used in Portuguese traditional cuisine, which may reduce the risk of insufficient uptake.

3.3. Potential Cardiovascular Benefit

As previously shown, all the foods considered present antioxidant components quantitatively dispersed along a certain range of values. Consequently, it was necessary to

calculate an average value (see Tables 1 and 2), which was used in the calculation of the cardiovascular benefit score.

Tables 5 and 6 show the results obtained for the total score for each of the selected fruits and vegetables, respectively.

Table 5. Potential cardiovascular benefit of fruits.

Fruits Criteria	Orange	Lemon	Strawberry	Apple	Grape	Pear	Watermelon	Melon	Banana	Loquat
High antioxidant capacity (FRAP values above 1)	•	•	•		•					
Presence of n-3 fatty acids										
Less than 2% saturated fat per 100 g	•	•	•	•	•	•	•	•	•	•
Less than 50 mg of cholesterol per 100 g	•	•	•	•	•	•	•	•	•	•
Free of trans fatty acids	•	•	•	•	•	•	•	•	•	•
More than 2.5 g of fiber per 100 g									•	
Less than 200 mg of sodium per 100 g	•	•	•	•	•	•	•	•	•	•
Potential cardiovascular benefit	5	5	5	4	5	4	4	5	5	4

Table 6. Potential cardiovascular benefit of vegetables.

Vegetables Criteria	Lettuce	Tomato	Potato	Carrot	Onion	Garlic	Zucchini	Cabbages	Sweet potato	Pumpkin
High antioxidant capacity (FRAP values above 1)		•			•					
Presence of n-3 fatty acids										
Less than 2% saturated fat per 100 g	•	•	•	•	•	•	•	•	•	•
Less than 50 mg of cholesterol per 100 g	•	•	•	•	•	•	•	•	•	•
Free of trans fatty acids	•	•	•	•	•	•	•	•	•	•
More than 2.5 g of fiber per 100 g				•		•			•	
Less than 200 mg of sodium per 100 g	•	•	•	•	•	•	•	•	•	•
Potential cardiovascular benefit	4	5	4	5	5	5	4	4	5	4

The results show a score for potential cardiovascular benefit of between 4 and 5 for the whole group of fruits and vegetables considered. The highest score in fruits was reached by orange, lemon, strawberry, grapes, melon and banana. Among vegetables, tomato, carrot, onion, garlic and sweet potato reached the higher score for potential cardiovascular benefit. In accordance with the nutrition composition of those two groups of foods, the contribution of n-3 fatty acids is absent or non-significant. Furthermore, it is interesting to find that to reach those score results, the least effective contributions in both food groups considered are from FRAP values and fiber. The contribution of FRAP values, considering the uses of an average value, as previously explained, is more relevant in fruits (FRAP value above 1 in 5 of 10 foods) than it is in vegetables (FRAP value above 1 in 2 of 10 foods).

4. Discussion

The present study, through the construction of comparative scales to assess the antioxidant potential and the potential cardiovascular benefit of the ten most consumed fruits and ten most consumed vegetables in Portugal revealed that: (i) among fruits, lemon, grapes and melon simultaneously exhibited the highest antioxidant potential values and the highest cardiovascular potential benefit; (ii) among vegetables, tomato and onion showed simultaneously similar top results. It is already known from the literature that all these fruits and vegetables are valuable sources of nutraceuticals.

A nutraceutical is a type of functional food or a component of food that offers therapeutic or health advantages, including the capacity to treat and prevent disease [28]. There is an array of bioactive compounds in plants known as secondary metabolites with nutraceutical properties that consumers could benefit from [29].

Moreover, they have also added value as dietary sources of bioactive compounds with an antioxidant action, beyond vitamins and minerals, obtained directly from whole foods or through commercial supplements. Departing from a literature review of available studies to quantify antioxidants present in foods and their average content, and the ten (10) most consumed fruits and vegetables in Portugal, we intended to compute this information in the context of an existing cardiovascular benefit score, and apply it to those fruits and vegetables. The score thus obtained can be used as a supporting tool for nutrition education to explain the full potential of those foods for health.

Epidemiological studies revealed that high fruit intake was associated with reduced mortality and morbidity from cardiovascular disease and some types of cancer, and the possible mechanisms were attributed to the antioxidant activity presented by the fruits [30,31].

In their review article, Cunha et al. (2016) [32] state that fruits and vegetables contain bioactive substances with protective effects, particularly antioxidants. These bioactive substances originate from the secondary metabolism of plants. The list of antioxidants introduced into the diet through the consumption of fruits and vegetables is quite extensive, highlighting three groups: vitamins (vitamin E and its major constituent α -tocopherol, and vitamin C), phenols, and carotenoids [33]. Among these compounds, polyphenols are the most abundant and possess numerous biological effects, such as free radical scavenging, inhibition of cell proliferation, antibiotic, antiallergic, and anti-inflammatory properties, thus playing an important role in the prevention of cancers and cardiovascular diseases [32].

There are many different antioxidants contained in fruits and vegetables, and it is very difficult to measure each antioxidant component separately. Additionally, several analytical methods for determining antioxidant potential have been developed in recent decades; however, not all have been systematically utilized to study various fruits and vegetables.

Jideani et al. (2021) [13] presented a table with the main antioxidant contents of some fruits and vegetables in mg/100 g fresh food. Furthermore, according to those authors, established protocols for the analysis and determination of antioxidant capacity in fruits and vegetables include oxygen radical absorbance capacity (ORAC), Trolox equivalent antioxidant capacity (TEAC), 2,2-azino-bis-3-ethylbenzthiazoline-6-sulfonic acid (ABTS), 1,1-diphenyl-2-picrylhydrazyl (DPPH), ferric reducing ability of plasma (FRAP), and vitamin C equivalent antioxidant capacity (VCEAC). A comprehensive comparison of the antioxidant activity among different fruit fractions was performed by Guo et al. (2003) [34]. In their study, the antioxidant activities of peel, pulp and seed fractions of 28 fruits were compared using the FRAP assay.

Therefore, studies using the FRAP assay were selected to establish a comparative basis among different products. The available data on antioxidant potential values was used to create the tables to refer to conventionally produced fruits and vegetables because we did not find sufficient and comparable data for foods produced through organic or other sustainable agricultural methods.

A comparison between conventional and organic fruits and vegetables would be of great interest since some recent studies have shown that plant-based foods grown organically have higher levels of certain bioactive compounds than foods produced through conventional methods. For example, a study presented by Worthington (2001) [35], compiled comparative data between organic and conventional foods, demonstrating that organic foods tend to have higher concentrations of vitamin C and phenolic compounds. Another study found higher levels of antioxidants in organically grown strawberries compared to conventionally grown ones. It was also observed that extracts from organic strawberries had a more pronounced effect on inhibiting cancer cell proliferation *in vitro* [36]. In a systematic literature review and comprehensive meta-analyses, Leifert (2014) [37] reviewed existing literature on the differences between organic and conventional crops. The results showed that organic crops, on average, contained higher concentrations of antioxidants such as polyphenols.

Olsson et al. (2006) [36], found higher levels of antioxidants in organically grown strawberries compared to conventionally grown ones. It was also observed that extracts from

organic strawberries had a more pronounced effect on inhibiting cancer cell proliferation *in vitro*.

The availability of natural antioxidant sources in food (such as herbs and spices, fruits and vegetables, and also marine algae), the safety profile of those natural sources, and the affordability when there is a proximity between the production site and the consumer make them a sustainable component of healthy diets [4].

The relevance of plant-based dietary patterns in the prevention of cardiovascular diseases and other non-communicable diseases (metabolic and cancer-related) have been established, providing a basis to support recommendations emphasizing their use to improve health [4]. It is worthwhile to mention that a plant-based diet means a diet with a higher intake of plant-based foods and a lower intake or exclusion of animal-based foods [38]. The beneficial effect of this diet on health is the result of a combination of lowering dietary risk factors (such as total fat and saturated fat) and improving dietary protective factors (such as antioxidants and fiber), in a delicate balance of pro-inflammatory and anti-inflammatory pathways, while also influencing the microbiome [4,39,40]. Antioxidants are compounds that inhibit the oxidation of other molecules and protect the body from the damaging effects of reactive oxygen species. These free radicals are generated either by normal cell metabolism, as an effect of toxicological external factors, or even as pharmacological secondary effects. Thus, they are responsible for premature aging and play a role in cardiovascular disease, degenerative diseases, chronic metabolic diseases and cancer [4].

Steinmetz and Potter [41] reviewed 206 human epidemiological studies and 22 animal studies on the relation between vegetable and fruit consumption and the risk of cancer. The protective effects of vegetables and fruits were evident for cancers of the stomach, esophagus, lung, oral cavity and pharynx, endometrium, pancreas and colon. Among the phytonutrients cited as potentially providing this protection were dithiolthiones, isothiocyanates, indole-3-carbinol, allium compounds, isoflavones, protease inhibitors, saponins, phytosterols, inositol hexaphosphate, vitamin C, D-limonene, lutein, folic acid, beta-carotene, lycopene, selenium, vitamin E, flavonoids, and dietary fiber.

The consumption of nutraceuticals may occur through a balanced diet, or an adjusted diet reinforcing the consumption of specific foods, and they may also be extracted and incorporated into isolated dietary supplements or used as ingredients in processed foods [42,43]. There is a wide and long-term use of food and herbs that goes beyond the mere interest as regular food [18]. The health interest in those bioactive components of food gives them a status as nutraceuticals, even considering that the concept has evolved over time and that the possibility of classification into several categories exists according to Salvatore et al. (2024) [18]. The consumption of a nutraceutical based on fruits and vegetables with a high polyphenol content has been shown to improve the parameters related to health benefits (oxidative and inflammatory biomarkers), including notable changes in the expression of catecholamines, such as dopamine [44].

A new challenge arises regarding further research to understand which botanical and commercial varieties are effectively consumed in Portugal and how much they really contribute to the intake of antioxidants in the country and across regions, as different varieties have a diverse predominance in the Portuguese regions. This knowledge may add value to educational interventions in communities, especially if they support the promotion of local production and the agricultural economy.

In the case of the most consumed vegetables considered in this study, those with the highest content are also the ones with the widest range in quantitative content. They have a broad usage in Portuguese traditional cuisine. So, along with reinforced education directed at promoting the Mediterranean diet, the knowledge about botanical varieties, territorial dispersion and possible seasonal variation, is all important information in delivering an even more effective contribution to health.

All of this data, alongside information about composition related to production methods, may contribute to the adjustment or development of cost-effective and scientifically

robust nutrition education methods and materials [45]. Consumers require accurate, applicable, and trustworthy sources of information about nutrition to support informed food and lifestyle choices [46]. Factors in the food environment affect eating behavior, and so, easily accessible healthy foods may provide an opportunity to value already existing eating behaviors or to change them to healthy dietary choices [47]. Widespread nutrition literacy and nutritional quality demand may drive investment in a deeper knowledge about food composition and health opportunities. Especially on a regional or local level, considering several cultural or behavioral settings and economic conditions, the success of nutritional education may be strongly influenced by local availability and affordability of food products. Thus, more information about food composition can be used to build effective nutrition education materials.

The information can also serve to build nutritional education materials that provide details about the antioxidant potential and cardiovascular potential of the food, as calculated in the previous section, along with its nutritional table and the bibliographic references that served as the basis for the information. This initiative promotes health literacy, serving as a catalyst for increasing the consumption of these products and aiming to create future impacts through change and health benefits, while also contributing to supporting healthy food production systems.

Nutraceuticals can serve as an alternative supplement to overcome nutritional deficiencies for a healthy lifestyle. They can also play a key role in disease management. How fruits and vegetables work as sources of nutraceuticals and supplements has been explored by different studies.

Fruits can be harnessed as potential sources of nutraceuticals owing to their natural composition of beneficial elements. The daily intake of fruits as well as vegetables can help reduce the risks of several chronic diseases and promote health [48]. Our work highlighted ten fruits and ten vegetables, with several of them studied and used by pharmaceutical or food industries as nutraceutical sources.

Citrus is the most cultivated fruit crop in the world and occupies a place of considerable importance in the country's economy. Almost 33% of the citrus fruits are processed for juice production and a great amount of waste, including peels, segment membranes, and seeds, is also produced. Citrus fruits consist of 45% juice, 26% pulp, 27% peels, and 2% seeds, and in all of these parts there are compounds suitable for nutraceuticals. Moreover, citrus peel has also shown nutraceutical potential, as we found in a recent review of Munir et al. [48].

The consumption of strawberries is gaining attention due to their antioxidant capacity, which plays an important role in controlling oxidative reactions in the human body and exhibiting anticarcinogenic effects. The most common phenolic compounds in strawberries with strong antioxidant capacity include flavonoids and phenolic acids which help induce an improvement in plasma antioxidant status and vitamin C concentrations. Moreover, there is evidence supporting the impact of strawberries on cardiovascular health and chemoprevention [49].

Grapes are one of the oldest fruit crops domesticated by humans. As the largest group of grape polyphenols, flavonoids are the main candidates considered for their biological properties, including, but not limited to, antioxidant, anti-inflammatory, anticancer, antimicrobial, antiviral, cardioprotective, neuroprotective, and hepatoprotective activities [50]. Furthermore, these authors also discuss the advantages of modern plant cell-based biotechnology as an alternative method to produce grape nutraceuticals and for improving their health qualities. More recently, a book chapter has explored grapes as a crop with high nutraceutical genetic diversity [43]. Another approach summarizes the benefits of drinking grape infusions and discusses the sustainable processes for extracting potential nutraceutical compounds from grapes and grape by-products, which are often considered as fermentation waste, and are discarded into the environment without proper treatment [51].

Melons belong to the Cucurbitaceae family and include many commercially important crops, encompassing diverse botanical/horticultural types that are widely grown across

temperate, subtropical, and tropical regions of the world. Characterizing the diverse melon cultivars from a nutritional perspective aid in crop improvement and the promotion of a healthy diet [52]. Carotenoids and chlorophylls are the main pigments in melon pulp and rind. Melon fruits also contain protein and sugars; the major antioxidants in melons include phenolic compounds, ascorbic acid, and carotenoids. Their seeds contain vitamin E and ω -3 fatty acids [53].

Bananas are widely popular as a key member of the Musaceae family and they are considered a rich source of several nutrients, especially bioactive compounds. In addition to bananas, their by-products, such as peel, pseudo-stems, leaves, and blossoms, are also rich in carbohydrates, protein, dietary fiber, vitamins and phenolic compounds [54].

Nutraceuticals derived from plant sources often require extensive research and development, as well as various stages of testing before being marketed safely. Compounds found in banana by-products have already been commercialized in the pharmaceutical industry as nutraceuticals [55].

For example, there are some interesting review studies focused on the nutraceutical potential of tomatoes [16]. On the other hand, some fruit and vegetable waste or by-products from the agrifood industry, namely tomatoes [56,57], sweet potatoes [58], and onions [59], have been deeply studied as nutraceutical sources.

Onions have the potential to be a valuable natural resource for the development of functional foods or nutraceuticals for the prevention and control of illnesses including obesity, diabetes, cancer, cardiovascular disease, and neurodegenerative disease [60]. Additionally, the skin waste of onions as a source for nutraceuticals was reviewed recently [61].

Raw white garlic, a fundamental food in both culinary and medicinal practices globally, as well as in Portugal, has gained attention for its potential health benefits. Despite its widespread use, clinical research has predominantly focused on aged black garlic or garlic extracts, leaving raw white garlic consumption in humans underexplored [62]. Garlic is a powerhouse of nutraceuticals known to possess several beneficial compounds, such as allicin, that are helpful in ameliorating numerous physiological conditions. Bioactive compounds in garlic (like allicin, alliin, allitridin, allicin, alliin, garlicin, diallyl sulphide, and diallyl disulphide) offer antioxidant and anti-inflammatory benefits, and assist in combating chronic diseases [63].

Allicin is a highly unstable molecule and, during processing, is rapidly transformed into a variety of organosulfur components. The enzyme alliinase, which is responsible for the conversion of alliin to allicin, is irreversibly destroyed in the acidic environment of the stomach. This explains why most garlic supplements contain garlic powder or granules, but lack allicin itself. Garlic alliinase could be encapsulated and coated with materials that would protect it from the harsh conditions of the stomach [64].

Observational studies, limited to Asian studies, reported the association of raw garlic consumption with improvements in important health outcomes, including cancer risk, cardiovascular disease, insulin homeostasis, and liver function. However, both clinical and observational studies were heterogeneous in design, participant characteristics, durations, and outcome measures [62].

Carrot is a significant source of vitamins (A, B, C) and beta carotene. Furthermore, they contain vitamins B, C, E, H, folic acid and pantothenic acid. Carrots are an important source of trace elements (K, Na, Ca, Mg, P, S, Mn, Fe, Cu and Zn) and polyphenols [65]. Recently, to develop carrot nutraceutical products, 64 genotypes from four different continents were evaluated for a range of morpho-nutritional variables [66]. A systematic review showed that numerous in vivo and in vitro research has revealed carrots' many health benefits, including cholesterol-lowering, anti-diabetic, antihypertensive, renoprotective, hepatoprotective, and the ability to facilitate the excretion of fats and bile by the liver [67]. In this review, pomace from carrots, which contains about 50% β -carotene, was recognized as a valuable byproduct that can be economically helpful for boosting culinary products such as biscuits, bread, and cakes, as well as preparing various functional goods.

Our study has a major limitation arising from the unavailability of data (at least using the FRAP assay) about fruits and vegetables produced and sold in Portugal. As a result, we had to rely on data that might not fully represent Portuguese food. Also, the data obtained from the literature refer to conventional fruit and vegetable farming. In a societal context of growing interest and demand for organic production, this represents an information gap to fill in future studies. This poses a challenge and provides a foundation for future studies to focus on the evaluation of total antioxidant capacity and potentially beneficial health components. In this context, the methodology used in the present work could be replicated to facilitate comparisons between organic and conventional foods.

The major interest of this study lies in having an available and simple tool to explain the full nutritional value of fruits and vegetables for use in nutritional education.

Nutrition education, from national policy to local action, benefits from knowledge about food products, helping to enhance consumer information and providing direction for effective interventions promoting healthy food choices, alongside promoting the ability to choose more sustainable production systems. An example of the practical application of this information is the use of scales that allow for converting complex scientific data into practical, simple and user-friendly information in food literacy initiatives.

5. Conclusions

Plant foods are significantly more important as a source of antioxidants in human diet than non-plant foods, although variations in food samples from diverse origins exist. Fruits and vegetables are essential components in a healthy diet. The Mediterranean diet is an example of a food pattern that traditionally includes the consumption of these products and values their diversity as a whole and their origin in terms of regional variation. Also, the growing interest in plant-based diets by consumers requires a careful selection of foods, since the mere adoption of plant foods does not mean an absence of unhealthy products, such as processed plant foods. Additionally, there is growing attention towards comparing conventional and organic food production and their influence on the nutritional quality of food.

Fruits and vegetables have been the focus of recent interest among researchers and health professionals for their role in human health and the prevention of chronic diseases. The evidence for the potential health-promoting and disease-preventing effects of the consumption of fruits and vegetables, as well as the use of their by-products is linked to their content in compounds that are natural sources of nutraceuticals.

This work highlights the antioxidant capacity and the cardiovascular protective potential of the ten most consumed fruits and the ten most consumed vegetables in Portugal according to a previous study conducted by the same authors. The main results showed that the fruits that simultaneously exhibited the highest antioxidant potential values and the highest cardiovascular potential benefit were lemon, grapes, and melon; among vegetables, the top rankings were found to be tomato and onion.

From these natural plant sources, including their by-products, nutraceuticals can be obtained for the food industry and pharmaceutical applications. Moreover, the available information about the antioxidant potential and cardiovascular protection of fruits and vegetables can be used in initiatives to promote health literacy and serve as a catalyst for increasing the consumption of these products. Similar approaches are desirable to translate complex scientific data into practical, simple, and user-friendly information for food literacy initiatives, including nutrition education materials, about the relative level of the potential cardiovascular benefits of a large diversity of food products.

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