

# Reevaluating Vitamin C in Human Nutrition: Dietary Reference Intakes, Food Sources, and Supplementation Practices

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**Abstract** Vitamin C (L-ascorbic acid) is an essential micronutrient that cannot be synthesized or stored by the human body, necessitating regular dietary intake to prevent deficiency-related conditions such as scurvy, which can be life-threatening. This review examines the pathophysiological mechanisms associated with vitamin C deficiency and evaluates current dietary reference intakes (DRIs), major dietary sources, and the role of supplementation in meeting physiological requirements. It also explores the physicochemical and molecular properties of vitamin C that affect its bioavailability, stability, and biological functions.

**Keywords:** acerola, ascorbic acid, camu-camu, food composition tables, food processing and technology, kakadu plum, vitamin C toxicity

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## 1. Introduction

This introduction is divided into two subsections, the first (1.1) addressing general aspects of vitamin C, and the second (1.2) exploring the physicochemical factors that influence this compound's bioavailability.

### 1.1. Overview of Vitamin C

Vitamins (Latin *vita* added to the English amine) were initially named in alphabetical order and then based on their chemical structure [1,2]. Hence, vitamin C, identified as L-ascorbic acid (or L-ascorbate), was isolated in the late 1920s by the Hungarian biochemist Albert von Szent-Györgyi (1893-1986) and has been produced by the industry since 1934 [2].

Human beings have lost the ability to synthesize vitamin C around 65 million years ago because of an enzymatic deficit (L-gulonolactone oxidase), and do not possess the vitamin store in the body, so they must consume foods (or supplements) rich in this micronutrient on a daily basis [2,3]. Besides humans, other animals, such as monkeys and guinea pigs, do not express the gene for the abovementioned enzyme and are susceptible to developing scurvy, unless daily vitamin C is given, it is worth emphasizing [4]. Thus, scurvy is a chronic nutritional deficiency caused by prolonged lack of vitamin C in the diet, further discussed ahead [5].

In fact, vitamin C has undeniable benefits for human

health, favourably impacting on epithelial integrity and function together with vitamins A (retinol) and D (calcitriol or yet 1,25-dihydroxycholecalciferol), micronutrient metabolism (e.g., iron, copper, and folic acid), neuropeptides (enzymatic amidation), lipoproteins (antioxidant effect on low-density lipoprotein or LDL), immune process, collagen synthesis, among other important roles [2,6,7]. Delving deeper into collagen synthesis, vitamin C is necessary for the production and maintenance of collagen (generic term), a complex protein (quaternary structure), forming the basis for connective tissues (bones, teeth, skin, and tendons) [8]. Recent research has reviewed the pathophysiology and clinical manifestations of vitamin C deficiency (or scurvy) according to age groups [7].

The clinical manifestations of scurvy are more severe in children (less than or equal to ( $\leq$ ) 17 years old) than in adults (between 18-59 years old) [7]. In addition, it is not uncommon to encounter asymptomatic adult patients who have subclinical vitamin C deficiency, with significantly lower laboratory values less than 0.2 mg/dL (but the threshold of vitamin C deficiency at which symptoms arise has not been defined yet) [7]. For example, among 172 patients of all ages examined in May 2024 in Manaus, Amazonas, Brazil, 14 adults (mean age 48 years) exhibited no symptoms of scurvy despite having very low blood levels of vitamin C (mean 0.09 mg/dL; unpublished personal data).

Scurvy manifestations should be contextualized with the socioeconomic environment (e.g., alcoholism, limited budget, mental incapacity) of elderly individuals (greater

than or equal to ( $\geq$ ) 60 years old) to be accurately detected in everyday clinical practice [7].

Data regarding the oldest-old individuals ( $\geq$  85 years old) are virtually non-existent [7]. Nevertheless, octogenarians and nonagenarians who consumed fresh fruits and vegetables daily were regularly followed in clinics throughout 2024 in Manaus, Amazonas, Brazil. They were asymptomatic for scurvy and showed normal blood levels of vitamin C (unpublished personal data).

## 1.2. Physicochemical Properties Influencing the Bioavailability of Vitamin C

The physicochemical characteristics of vitamin C greatly influence its bioavailability, i.e., its rate and extent/amount of absorption of unchanged drug from its dosage form, as well as some of its biological properties, justifying the brief comments below [9].

Vitamin C is a weak organic acid that looks like a crystalline and white compound [10]. Weak organic acids are only partially ionized, and depending on pH (or potential of hydrogen), will exist as either the undissociated acid form, the dissociated acid form, or a mixture of both [11]. Weak organic acids are more inhibitory to microorganisms than strong acids because they are lipophilic and penetrate the plasma membrane, thus acidifying the cell interior (e.g., inactivating the Gram-negative bacterium *Escherichia coli* and the Gram-positive bacterium *Listeria monocytogenes*) [12]. But in reality, vitamin C displays significant antibacterial activity at acidic pH against all bacterial strains [13]. Of note, studies in vivo and in vitro have shown that vitamin C inhibits the Gram-negative spiral bacterium *Helicobacter pylori*, a well-known risk factor for gastric carcinoma, and also the Gram-positive rod-shaped bacterium (or bacillus) *Mycobacterium tuberculosis* (in vitro) [14,15,16,17,18].

*Candida albicans* is considered a model for studying fungal pathogens [19]. The antifungal activities of vitamin C are complex and involve, for example: (1) regulation of the Fenton reaction (i.e., the reaction between iron and hydrogen peroxide ( $H_2O_2$ ), generating hydroxyl radical (OH)), destroying *C. albicans*; (2) interference with yeast-to-filamentous form (or hypha) transition in *C. albicans*, a well-established virulent trait of this opportunistic microorganism [20,21].

The COVID-19 pandemic has renewed the interest in vitamin C and its antiviral properties, opening new perspectives in the vitamin research and potential therapeutic uses, as revised in a recent article [2].

On the other hand, vitamin C is highly soluble in water, but very labile in solution and readily destroyed by heat, oxidation, alkali, and light [22,23,24]. Because of its sensitivity to air and light, vitamin C must be appropriately kept in a closed container, protected from light [24]. Even so, vitamin C loss during prolonged storage of milk is attributable to the dissolved oxygen present in the dairy product [23]. Similarly, oxygen ingress at bottling or via the closure after bottling is an important factor that contributes to the loss of vitamin C in white wine [25].

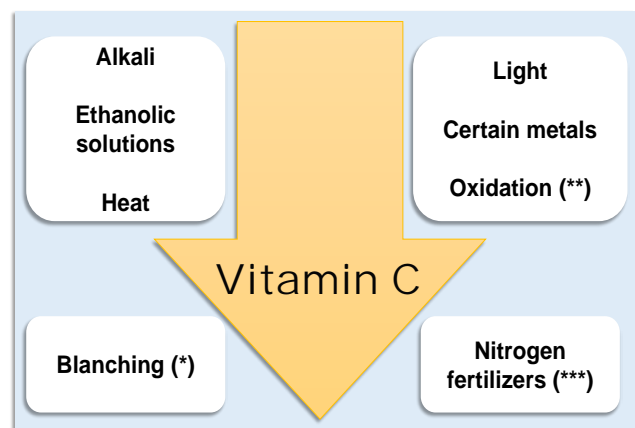
In reality, vitamin C occurs naturally in many wine-making fruits, and the industry also uses the vitamin as an antioxidant and color stabilizer in the production of

alcoholic beverages, including white wine, wine coolers, alcopops (a collective term that refers to flavored alcoholic beverages, or FABs, among other synonyms), and fruit liqueurs [26,27]. However, during storage, vitamin C degradation in ethanolic solutions follows a first-order reaction, i.e., a reaction that proceeds at a rate that depends linearly only on one reactant concentration; the degradation and browning (or Maillard reaction) rates increasing with the increase of ethanol concentration [26,28].

In a study of the stability of vitamin C in different beverages, vitamin C was stable in orange juice at the original pH values, whereas beer was also a good matrix for vitamin C addition, but only under pH 4 and at low storage temperature (4°C) [29].

Vitamin C provides considerable protection against white wine oxidation under conditions of low oxygen, having the ability to remove oxygen from the beverage more quickly than would be the case in its absence [25]. But, different from white wine, vitamin C is seldom used in red wine as the higher concentration of phenolic compounds (especially flavonoids) in red wine negate the need for further antioxidant addition (actually, the antioxidant potential of flavonoids is more robust than that of vitamin C and vitamin E—also known as  $\alpha$ -tocopherol) [5,30,31,32].

A study on factors influencing the preservation rate of vitamin C in acerola cherry pulp (Malpighiaceae family), rich in the vitamin (up to 4,000 mg or 4 g/100 g), demonstrated that this fruit is suitable for storing at the temperature of 5 °C, pH value between 3.2 to 3.5, no light, sealed, and without metal ions such as ferrous iron ( $Fe^{2+}$ ), ferric iron ( $Fe^{3+}$ ), cuprous ion ( $Cu^+$ ), cupric ion ( $Cu^{2+}$ ), and aluminium ion ( $Al^{3+}$ ) [33]. The effect of these physicochemical factors can differ depending on the fruit species, as seen with the yellow bell pepper (Solanaceae family) [34] (Figure 1). Other mechanisms of vitamin C degradation, including the enzymatic one (e.g., L-ascorbate oxidase activity), are discussed in the following references [35,36,37,38,39].



(\*): Blanching, i.e., a short heat treatment inactivating natural enzymes in vegetables, reduces vitamin C content during the operation, but limits more decreases during the posterior frozen-storage of horticultural products [40,41,42]. (\*\*): Sugars (e.g., fructose, glucose) or sugar alcohols (e.g., sorbitol, maltitol) decrease oxygen solubility, leading to less oxygen availability for degradation of vitamin C [43,44,45]. (\*\*\*) At high rates, they make up a preharvest factor reducing the concentration of vitamin C in many fruits and vegetables [40].

**Figure 1.** Examples of physicochemical factors that decrease vitamin C content in food items

## 2. Dietary Reference Intakes (DRIs) for Vitamin C

Dietary Reference Intakes (DRIs) refer to a set of four nutrient-based reference values: Recommended Dietary Allowance (RDA), Adequate Intake (AI), Tolerable Upper Intake Level (UL), and Estimated Average Requirement (EAR) [6,46]. Each of these values serves a specific purpose and has associated advantages and limitations, which are not discussed further here.

The RDA represents the daily intake level sufficient to meet the nutrient requirements of nearly all (97-98%) healthy individuals [47]. It is often used to plan nutritionally adequate diets for individuals [47].

The AI is the intake level assumed to ensure nutritional adequacy and is established when evidence is insufficient to develop an RDA. [47].

Table 1. Daily DRIs for Vitamin C (\*)

Age groups	RDA	AI	UL	EAR
Children				
0-6 months		40 mg		
7-12 months		50 mg		
1-3 years	15 mg		400 mg	13 mg
4-8 years	25 mg		650 mg	22 mg
9-13 years ♂	45 mg		1,200 mg	39 mg
14-18 years ♂	75 mg		1,800 mg	63 mg
9-13 years ♀	45 mg		1,200 mg	39 mg
14-18 years ♀	65 mg		1,800 mg	56 mg
Adults ♂	90 mg		2,000 mg	75 mg
Adults ♀	75 mg		2,000 mg	60 mg
Pregnancy				
14-18 years	80 mg		1,800 mg	66 mg
19-30 years	85 mg			70 mg
≤ 18 years			1,800 mg	
19-50 years			2,000 mg	
31-50 years	85 mg		2,000 mg	70 mg
Lactation				
14-18 years	115 mg		1,800 mg	96 mg
19-30 years	120 mg			100 mg
≤ 18 years			1,800 mg	
19-50 years			2,000 mg	
31-50 years	120 mg		2,000 mg	100 mg
Smokers ♂ (**)	90 mg + 35 mg			
Smokers ♀ (**)	75 mg + 35 mg			
Elderly ♂	90 mg		2,000 mg	75 mg
Elderly ♀	75 mg		2,000 mg	60 mg

(\*): Adapted from [46]. ♂: male; ♀: female; ≤: less than or equal to; +: plus. (\*\*): Smokers experience increased oxidative stress and vitamin C metabolism, raising their recommended intake by 35 mg/day [46]. Some age groups overlap but are included for reference.

The UL is the maximum daily intake level unlikely to cause adverse health effects [47].

The EAR is the average daily intake level estimated to meet the requirements of 50% of healthy individuals [47]. It is usually used to assess the nutrient intakes of groups and to plan nutritionally adequate diets for them [47]. It can also be used to assess the nutrient intakes of individuals [47].

The scientific data used to develop the DRIs come from both observational and experimental studies [46]. The DRIs provide estimates of nutrient intakes that are adequate for the vast majority of individuals within a specific population and are used by professionals to assess and plan diets for both individuals and groups [48]. The RDA is particularly noteworthy because it is designed to meet the nutrient needs of nearly all healthy individuals; this is worth emphasizing [46].

The DRIs for vitamin C are based on estimated tissue levels considered sufficient to provide antioxidant protection with minimal urinary loss (Table 1) [46,49]. This topic is revisited in the therapeutic discussion (see Section 4).

## 3. Dietary Sources of Vitamin C

### 3.1. Exceptional Sources

Vitamin C is widespread throughout the plant kingdom (Plantae) [50] and is found in particularly high concentrations in fresh fruits and vegetables [51]. The following five fruits have exceptionally high vitamin C content.

#### 3.1.1. Kakadu Plum

Kakadu plum (*Terminalia ferdinandiana* Exell.) is an endemic plant species of the Combretaceae family that grows in the monsoonal tropical climate of northern Australia [52]. It is so designated because most official botanical records of the plant are from the Mirrar homelands and the World Heritage-listed Kakadu National Park; however, the tree grows prolifically throughout northern Australia, above the Tropic of Capricorn [53]. It is a small, semi-deciduous tree with broad, light green leaves, bearing ovoid, yellowish-green fruit approximately 2.5 cm long and 1 cm in diameter, with a succulent outer layer surrounding a hard stone [54]. It contains the highest known concentration of vitamin C among fruits, with levels that can exceed 5 g/100 g [55].

Kakadu plum is primarily used in food products such as jams, sauces, and relishes, as well as in the seafood industry to extend the shelf life of cooked prawns.

#### 3.1.2. Camu-camu

Camu-camu (*Myrciaria dubia* (Kunth) McVaugh) is a small, bushy riverside tree belonging to the Myrtaceae family [56]. It is native to the Amazon rainforest and commonly found in Colombia, Ecuador, Peru, Bolivia, and Brazil [57]. The fruit is a globose berry, 1-3 cm in diameter, with a circular hypanthial scar at the apex and a thin skin [57,58]. It is green when immature, turning reddish-brown to purple-black as it ripens (Figure 2) [57,58]. The pulp is fleshy and soft at maturity, enclosing 2-3 seeds [57]. The fruit has a high vitamin C content, approaching 3 g per 100 g (i.e., 2,994 mg/100 g) [57,58].

Camu-camu fruits are processed into various forms—including powders, juices, and supplements—due to their tart, acidic taste when consumed fresh. They are also used in the production of jellies, sherbets, and purees. Lastly, camu-camu may serve as a raw material in the production

of caxiri, a traditional fermented beverage of Tupi origin from the Amazon region of Brazil.



**Figure 2.** Camu-camu fruits at different ripening stages, purchased at an open market in Manaus (Amazonas, Brazil)

### 3.1.3. Acerola

Acerola (*Malpighia puniceifolia* L.), a member of the Malpighiaceae family, is native to South and Central America, with Brazil hosting many of the world's largest plantations due to the species' favorable adaptation to local soil and climate conditions [59].

A superfruit may be defined as a fruit believed to provide significant health benefits beyond basic nutritional value [60]. Acerola is considered a superfruit due to its exceptionally high vitamin C content [61]. In this fruit, vitamin C levels are notably high, ranging from 623,2 to 4,023 mg/100 g [62,63].

Based on my clinical experience in Manaus, Amazonas, Brazil, patients who report growing acerola in their backyard and consuming its juice daily consistently present with elevated serum vitamin C levels (unpublished personal observations). In addition to beverages, acerola is used in dietary supplements and even in meat products (see also Subsection 3.2.2).

### 3.1.4. Rose Hips

Rose hips, which are pseudofruits, are aggregate structures composed of several achenes—the true seed-containing fruits—enclosed within an enlarged, red, fleshy floral cup known as the hypanthium [64].

Rose hips are produced by various species of wild and cultivated roses, most commonly by *Rosa canina* L., *Rosa rugosa* Thunb., and other members of the *Rosa* genus. The genus *Rosa*, encompassing all rose species, is widely cultivated across diverse agroecological regions worldwide.

Rose hips have been used in herbal medicine for over 2,000 years, but only recently has research begun to clarify the specific mechanisms by which they affect human health, such as their antioxidant, anti-inflammatory, antidiabetic, lipid-lowering, and anti-obesogenic activities [64,65]. Among their key bioactive components, vitamin C stands out due to its abundance and biological significance. Notably, fresh rose hips contain high levels of vitamin C (727-2,712 mg/100 g), depending on the species, harvest time, and post-harvest handling conditions [66,67].

Interestingly, a study of five ripening stages in four

species/cultivars (cv.) of the *Rosa* genus showed that the highest vitamin C content in *R. rugosa*, *R. rugosa* 'Alba', and *R. rugosa* 'Rubra' was found at ripening Stage I (1972.63 mg/100 g, 1139.93 mg/100 g, and 1646.23 mg/100 g, respectively), whereas in *R. canina*, the highest content was observed at ripening Stage IV (1351.74 mg/100 g) [68].

Rose hips have a variety of culinary applications, including syrups, jellies, soups, seasonings, sauces, and infusions.

### 3.1.5. Indian Gooseberry

*Phyllanthus emblica* L., a synonym of *Emblica officinalis* Gaertn., is a deciduous tree belonging to the family Phyllanthaceae and commonly known as amla, aonla, or Indian gooseberry [69,70]. It is said to be the very first tree to have originated on Earth, according to ancient Indian mythology [70].

It is found throughout the tropical and subtropical regions of India, Sri Lanka, and Malacca, and is also abundant in the deciduous forests of Madhya Pradesh, Darjeeling, Sikkim, and Kashmir [71].

The arrangement of aonla fruits along the branches gives the impression that the plant bears flowers on its leaves—a characteristic reflected in the genus name *Phyllanthus*, which literally means "leaf flower" [72].

The fruit is reported to be very rich in vitamin C ( $\geq 600$  mg/100 g) [71,72,73].

Indian gooseberries are primarily used in culinary applications (e.g., pickles, candied fruits, juices), in Ayurvedic medicine—the traditional Indian system of medicine (e.g., as a rejuvenative and for treating various ailments), and in beauty products (e.g., hair and skincare).

In addition, Table 2 lists other fruits and vegetables rich in vitamin C.

**Table 2. Vitamin C Content in Fruits and Vegetables (\*)**

Common names, scientific names, and botanical families	Content (mg/100 g)
Cashew, raw ( <i>Anacardium occidentale</i> L., Anacardiaceae)	219.3
Yellow bell pepper, raw ( <i>Capsicum annuum</i> L., Solanaceae)	201.4
Guava, white, raw, with skin ( <i>Psidium guajava</i> L., Myrtaceae)	99.2
Guava, red, raw, with skin ( <i>Psidium guajava</i> L., Myrtaceae)	80.6
Kiwi, raw ( <i>Actinidia deliciosa</i> (A. Chev.) C.F. Liang & A.R. Ferguson, Actinidiaceae)	70.8
Red (or green) pepper, raw (1/2 cup) ( <i>Capsicum annuum</i> L., Solanaceae)	65.0
Bilimbi, raw ( <i>Averrhoa bilimbi</i> L., Oxalidaceae)	60.95
Star fruit, raw ( <i>Averrhoa carambola</i> L., Oxalidaceae)	60.9
Watercress, raw ( <i>Rorippa nasturtium-aquaticum</i> (L.) Hayek, Brassicaceae)	60.1
Broccoli, cooked (1/2 cup) ( <i>Brassica oleracea</i> L., Brassicaceae)	60.0
Kale, cooked (1 cup) ( <i>Brassica oleracea</i> L., Brassicaceae)	55.0
Sweet potato, vacuum can (1 cup) ( <i>Ipomoea batatas</i> (L.) Lam., Convolvulaceae)	50.0
Brussels sprouts, cooked (1/2 cup) ( <i>Brassica oleracea</i> L., Brassicaceae)	50.0

(\*): Adapted from [62,74,75].

As observed with rose hips (see Subsection 3.1.4), the composition of fruits and vegetables depends on both the cultivar and the stage of ripeness—factors often overlooked in research. Additionally, specifying the method of food preparation is essential, as it significantly affects nutritional content.

Finally, both bilimbi and star fruit may pose health risks due to their high levels of two bioactive compounds: oxalate, which is nephrotoxic, and caramboxin, which is neurotoxic [76,77,78,79,80]. More specifically, caramboxin is a non-peptide amino acid toxin with potent excitatory, convulsant, and neurodegenerative properties [80]. However, its neurotoxicity is particularly evident in individuals with pre-existing kidney conditions [78,81]

### 3.2. Emerging Sources

This subsection highlights two noteworthy and unconventional dietary sources of vitamin C: camel milk (3.2.1) and vitamin C–fortified meat products, such as sausages (3.2.2).

#### 3.2.1. Camel Milk

In many mammalian species—including ruminants (e.g., cows) and non-ruminants such as tylopods (e.g., camels)—vitamin C is believed to be synthesized in the liver from D-glucose via the glucuronic acid pathway [82,83,84,85]. In these animals, the need for exogenous vitamin C supplementation is often overlooked [85].

A study by Barakat and Abdalla (1965) reported that camel liver from 120 specimens contained a maximum of 74.33 mg, a minimum of 38.73 mg, and a mean of 58.06 mg of vitamin C/100 g of liver [86]. In another study involving 3,429 camels, the highest concentrations of vitamin C were found in the adrenal glands (151 mg/100 g of wet tissue) and the lowest in the heart (8 mg/100 g of wet tissue) [87]. These values were not influenced by seasonal variation [87].

Lactation may be defined as the integrated process of milk synthesis, secretion, and excretion, beginning at calving and continuing until natural or induced drying-off in the lactating female [88]. Camel lactation lasts approximately 12 months, with a progressive increase in vitamin C concentration in the milk throughout the lactation period [89,90].

The high vitamin C content of camel milk has been reported in several studies [91,92,93]. Compared to the milk of other species, camel milk contains 52 mg/L, whereas cow, buffalo, sheep, goat, human, donkey, and mare's milk contain 27, 22, 29, 16, 35, 49, and 61 mg/L, respectively [92]. This high vitamin C content lowers the pH of the milk, thereby stabilizing it and delaying cream separation for longer periods compared to the milk of other livestock species [91]. These and other biotechnological properties make camel milk a key dietary component in arid and semi-arid regions, where access to green foods is limited [94]. Africa is home to approximately 87.1% (32.7 million) of the world's camels [91].

Due to its richness in bioactive compounds, camel milk is considered a functional food—i.e., a food that provides health benefits beyond basic nutritional value [95,96].

As noted earlier (see Subsection 1.2), vitamin C is readily degraded by heat and other physicochemical

factors. In particular, camel liver loses more vitamin C during frying (44.20 mg) than during roasting (23.19 mg) [86]. In addition to heat treatment, other factors—such as parasitic infections (e.g., trypanosomiasis)—also contribute to reduced vitamin C levels in camel liver [84]. Furthermore, low blood levels of vitamin C in camels may impair resistance to infectious diseases, potentially perpetuating a vicious cycle [82].

Camel milk has attracted growing scientific interest due to its high overall biological value (as mentioned above) and, in particular, its elevated vitamin C content. Nonetheless, it is important to note that the European Food Safety Authority (EFSA) states that, to claim a contribution to the maintenance of normal immune function during and after intense physical exercise, a food must provide at least 200 mg of vitamin C per day in addition to the normal diet—a quantity that can be easily achieved through a balanced intake [97]. Notably, a 250 mL serving of camel milk provides approximately 23.3% of the recommended dietary allowance (RDA) for vitamin C in humans (as discussed in Section 2) [98].

#### 3.2.2. Vitamin C–Fortified Meat Products

A fortified food may be defined as one to which macronutrients and/or micronutrients have been added using specific technological strategies to enhance its nutritional profile [99].

Sausages, in particular, are valued primarily for their flavor and, to a lesser extent, for their versatility—making them a popular choice across diverse occasions and cuisines. Sausages are quite common in the Norwegian diet, yet their vitamin C content is listed as zero in the Norwegian Food Composition Table, as well as in the food composition tables of several other countries [100].

One potential strategy to address the nutritional limitation of highly valued food sources such as meat products is the addition of vitamin C to sausages as an antioxidant [100]. When recalculating vitamin C intake in adults and adolescents using updated values from the most recent Norwegian national dietary surveys, total intake was found to increase by 3–10% [100].

On the other hand, the direct addition of vitamin C to meat products is challenging—not only because it is highly unstable at meat pH, promoting lipid oxidation, but also because its use is often prohibited due to its ability to stabilize meat color, which is considered a form of adulteration by consumers [101,102]. Moreover, it may mask quality changes, such as those resulting from microbiological activity [102].

As meat consumption increases, consumers are increasingly demanding meat products that contain functional ingredients with beneficial health effects, rather than merely serving as conventional foods [103]. Further research is warranted in this field.

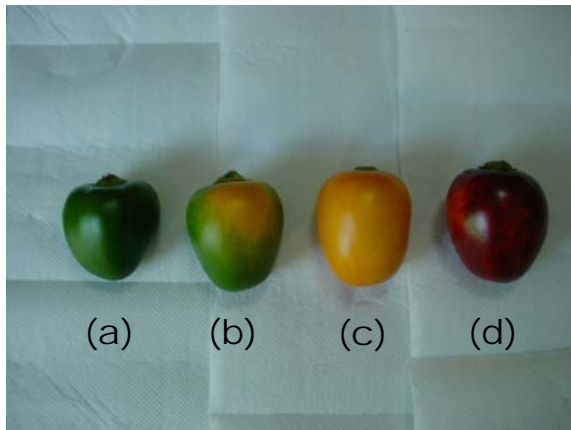
### 3.3. Intermediate Sources

Intermediate sources of vitamin C refer to foods that contain a moderate amount of the vitamin, falling between high and low levels, such as certain fruits and vegetables.

Vitamin C content in fruits may vary depending on the tissue examined (e.g., peel, pulp, and placenta) and the stage of ripeness (i.e., green, turning, ripe, and fully ripe),

as previously discussed in relation to rose hips [68].

For instance, in cubiu, also known as cocona (Figure 3)—a fruit from the Solanaceae family—the vitamin C content in the peel (mg/100 g fresh weight) gradually increases from the green stage (20.230), through the turning stage (23.170), to the ripe (27.148) and fully ripe stages (32.452) [6,104]. In the pulp, vitamin C content (mg/100 g fresh weight) increases from the green stage (16.367) to the turning stage (21.268), then returns to near-initial levels at the ripe stage (16.886), and slightly decreases at the fully ripe stage (13.139) [6,104]. In the cubiu placenta, vitamin C content (mg/100 g fresh weight) is higher than in the pulp at the green stage (17.809), shows little variation between the turning stage (22.248) and the ripe stage (22.709), and increases again at the fully ripe stage (24.842) [6,104].



**Figure 3.** Cubiu fruits (*Solanum sessiliflorum* Dunal) at the green stage (a), turning stage (b), ripe stage (c), and fully ripe stage (d)

**Table 3. Vitamin C Content in Fresh Fruits and Vegetables (\*)**

Common names, scientific names, and botanical families	Content (mg/100 g)
Arugula ( <i>Eruca sativa</i> Mill., Brassicaceae)	46.3
Red and white currants ( <i>Ribes rubrum</i> L., Grossulariaceae)	41.0
Mango ( <i>Mangifera indica</i> L., Anacardiaceae)	36.4
Pineapple ( <i>Ananas comosus</i> (L.) Merr., Bromeliaceae)	34.6
Swiss chard ( <i>Beta vulgaris</i> L., Amaranthaceae)	26.9
Tangerine ( <i>Citrus reticulata</i> Blanco, Rutaceae)	26.7
Banana ( <i>Musa × paradisiaca</i> L., Musaceae)	21.6
Tomato with seeds ( <i>Solanum lycopersicum</i> L., Solanaceae)	21.2
Blackberries ( <i>Morus nigra</i> L., Moraceae)	21.0
Passion fruit ( <i>Passiflora edulis</i> Sims, Passifloraceae)	19.8
São Paulo zucchini ( <i>Cucurbita verrucosa</i> L., Cucurbitaceae)	17.5
Jackfruit ( <i>Artocarpus heterophyllus</i> Lam., Moraceae)	14.8
Iceberg lettuce ( <i>Lactuca sativa</i> L., Asteraceae)	11.0
Abiu ( <i>Pouteria caimito</i> (Ruiz & Pav.) Radlk., Sapotaceae)	10.3
Strawberries ( <i>Fragaria vesca</i> L., Rosaceae)	10.0

(\*): Adapted from [62,105,106].

Thus, cubiu is a fruit rich in vitamin C—particularly in the peel and placenta at the fully ripe stage—and should be considered a palatable dietary source of this essential micronutrient [6,104]. Additionally, understanding the vitamin C content in the edible parts of cubiu during ripening may support its use in health promotion and disease prevention [6,104].

To sum up, intermediate sources of vitamin C include various fresh fruits and vegetables, as shown in Table 3.

### 3.4. Low Vitamin C Sources

In contrast to fresh fruits and vegetables—and as previously noted—meat products are generally poor sources of vitamin C. For instance, chicken contains 2.3 mg/100 g, while pork contains 0.9 mg/100 g; vitamin C is undetectable in turkey, lamb, and veal [107]. Likewise, the edible portions of fish contain no appreciable amount of vitamin C [108].

## 4. Vitamin C Supplementation: Daily Use and Considerations

When nutritional assessments reveal a deficiency in essential nutrients—such as vitamin C and key minerals—appropriate supplementation should be recommended to restore adequate levels and prevent deficiency-related conditions [109]. Today, vitamin supplementation plays a regular and important role in health and nutrition care, complementing fortified foods and improved dietary practices in addressing deficiencies such as scurvy [110].

Vitamin supplements fall under the broader category of dietary supplements, which refer specifically to food products added to the regular diet that provide nutritional substances—such as vitamins and minerals—or compounds with physiological or nutritional effects [111]. These may include amino acids, essential fatty acids, fibers, or plant extracts, and are typically offered in pre-dosed forms [111].

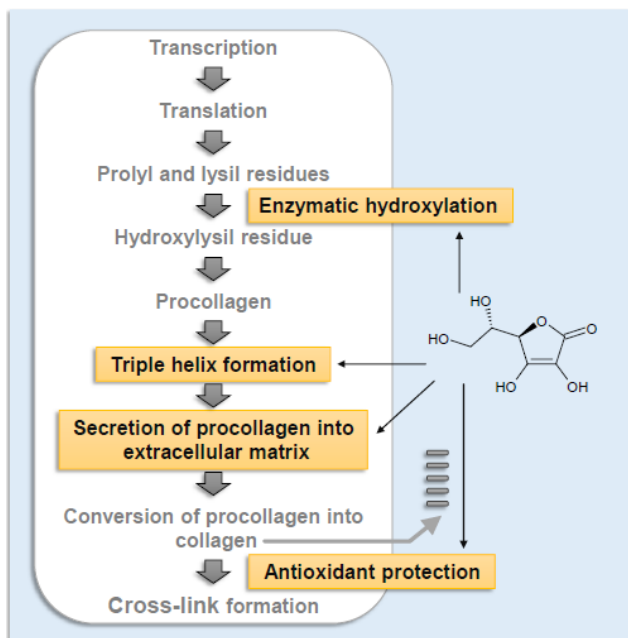
Dietary supplements are intended for ingestion—specifically, they must be swallowed [112]. As such, topical or inhaled products do not qualify as dietary supplements [112]. They are available in a wide range of forms, including pills, tablets, capsules, gummies, softgels, liquids, and powders [112].

Although gummies can be an appealing delivery form for vitamin C, this micronutrient may contribute to tooth enamel erosion, especially when consumed frequently or in high doses [8]. In addition, at elevated concentrations, vitamin C—and other supplements—may exhibit pro-oxidant activity, particularly in the presence of transition metals such as iron, via Fenton chemistry [8,46,113]. In this context, vitamin C supplements enhance iron absorption, potentially increasing the risk of iron overload in susceptible individuals, such as those with hereditary hemochromatosis or certain chronic conditions [8,46].

The rationale for consistent vitamin C supplementation is further supported by understanding the biological consequences of chronic deficiency. Scurvy, a disease virtually eliminated in many populations but still possible under restrictive diets, arises from prolonged insufficiency of this vitamin. It results in impaired metabolic processes,

especially those involving collagen synthesis, as discussed below [7].

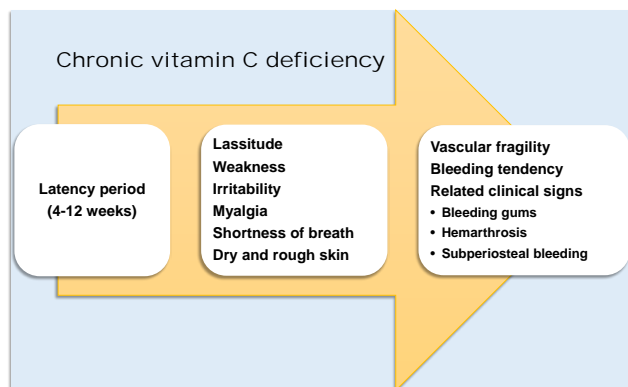
As described earlier in this work, vitamin C is essential for the production and maintenance of collagen—the most abundant structural protein in the body, responsible for connecting and supporting tissues such as skin, bones, tendons, muscles, cartilage, and internal organs [6,114]. The majority of human collagen consists of Types I and III [115] (Figure 4).



(\*): Adapted from [116,117,118,119,120].

**Figure 4.** Schematic representation of the role of vitamin C in multiple steps of collagen synthesis (highlighted in yellow) (\*)

Collagen turnover is relatively slow, with a half-life of approximately 70 days [121]. However, insufficient vitamin C disrupts its synthesis and stability, leading over time to the characteristic clinical features of scurvy—such as increased vascular fragility, bleeding tendencies, and poor wound healing [7]. This also explains the latency period observed before scurvy manifests clinically in adults [7,122] (Figure 5).



(\*): Adapted from [7,122].

**Figure 5.** Clinical manifestations of scurvy in adults (\*)

As discussed in Section 2, daily vitamin C requirements vary according to sex, age, and dietary source. Readers are

encouraged to revisit that section for a detailed understanding of individual needs and intake recommendations.

## 5. Conclusion

DRIs represent a substantial effort to provide a scientific rationale for the proper clinical application of nutrients—in this case, vitamin C—while also accounting for different age groups.

Nutraceuticals—also known as functional or even medical foods—are no longer just biomedical terms, but the tangible expression of nutrient-dense foods. Fruits such as Kakadu plum, camu-camu, acerola, rose hips, and Indian gooseberry are justifiably considered superfoods and warrant further scientific investigation.

With all the advances in food science, the ancient wisdom of Hippocrates' aphorism—'Let food be thy medicine'—seems to be more fully appreciated today. Nonetheless, significant hurdles and knowledge gaps must still be addressed before this enduring Hippocratic insight can be fully realized.

Regarding dietary sources of vitamin C, it is important to classify them—as attempted in the present work—to facilitate an objective and timely choice when making dietetic prescriptions. However, on a daily basis, combining all available food sources will not only meet vitamin C requirements but also enrich the diet with other essential nutrients and bioactive compounds. Therefore, no source of vitamin C should be overlooked, regardless of whether its content is moderate or even low.

It is essential to educate patients—regardless of age—and dispel any doubts about the ongoing need to consume vitamin C-rich foods to prevent scurvy and its harmful consequences.

If cultural or socioeconomic taboos exist surrounding the consumption of fresh fruits and vegetables—particularly among children and individuals with obesity, who often consume more calorie-dense foods—laboratory tests should be conducted and will likely reveal significantly low blood levels of vitamin C. It will then be crucial to inform patients about the need to take vitamin C supplements consistently every day without interruption. During the consultation, patients with vitamin C deficiency may be advised on appropriate daily supplementation strategies.

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## Conflict of Interest

The author declares no conflict of interest.

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