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Celebrating the International Year of Fruits and Vegetables

Nutrients and bioactive compounds naturally packed in fruits and vegetables

an innovative tool for public policies

Nutrientes y compuestos bioactivos envasados naturalmente en frutas y hortalizas

una herramienta innovadora para las políticas públicas

Nutrientes e compostos bioativos naturalmente embalados em frutas e vegetais

uma ferramenta inovadora para políticas públicas

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Abstract

Fruit and vegetable consumption contributes essential nutrients and bioactive compounds to maintain optimal health, with a positive impact on the physical, mental, and social life. Evidence shows that the daily intake of different vegetables mitigates the risk of micronutrient deficiencies and non-communicable, chronic, serious, and/or fatal diseases. To promote consumption, public policies require knowledge of fruit and vegetable properties, nutrient content, and the particular effects on the new aspects of life quality such as antiaging or immunity and the impact of agricultural practices, processing, conservation and domestic preparation on these properties. The first section of this review emphasizes the nutrient content in fruits and vegetables, functional bioactive compounds, bio-accessibility, and alterations induced by production systems and/or postharvest storage, variety, and fruit or vegetable physiological state. A second and special section deals with fruits and vegetables produced in Uruguay, showing recent research carried out in the country, and a third section refers to the perspectives for the application of public policies and promotional policies for consumers, of this special health marker associated with vegetables.

Keywords: vegetables, nutrition, human health, production system, processing

Resumen

El consumo de frutas y hortalizas aporta nutrientes esenciales y compuestos bioactivos para mantener una salud óptima, con impacto positivo en una vida física, mental y socialmente saludable. Existe evidencia de que la ingesta diaria de diferentes vegetales mitiga el riesgo de deficiencias de micronutrientes y enfermedades no transmisibles, crónicas, graves y/o fatales. Las políticas públicas para promover el consumo requieren del conocimiento sobre las propiedades de frutas y hortalizas, el contenido de nutrientes y los efectos particulares sobre nuevos aspectos de la calidad de vida, como el antienvejecimiento o la inmunidad, y el impacto de las prácticas agrícolas, procesamiento, conservación y preparación doméstica sobre estas propiedades. En esta revisión, la primera sección enfatiza en el contenido de nutrientes en frutas y verduras, compuestos bioactivos funcionales y bioaccesibilidad, y la modificación inducida por el sistema de producción y/o el almacenamiento poscosecha, la variedad y el estado fisiológico del vegetal. Una segunda sección trata sobre frutas y verduras producidas en Uruguay, mostrando las recientes investigaciones realizadas en el país. Y la tercera sección trata sobre las perspectivas para la aplicación de políticas públicas y políticas de promoción para los consumidores de un especial marcador de salud asociado a los alimentos vegetales.

Palabras clave: vegetales, nutrición, salud humana, sistemas de producción, procesamiento

Resumo

O consumo de frutas e vegetais fornece nutrientes essenciais e compostos bioativos para manter uma saúde ótima, com um impacto positivo na vida física, mental e socialmente saudável. Há evidências de que a ingestão diária de diferentes vegetais mitiga o risco de deficiências de micronutrientes e doenças não transmissíveis, crônicas, graves e / ou fatais. Políticas públicas para promover o consumo requerem conhecimento sobre as propriedades de frutas e vegetais, o conteúdo de nutrientes e os efeitos particulares sobre novos aspectos da qualidade de vida, como anti-envelhecimento ou imunidade e o impacto das práticas agrícolas, processamento, conservação e preparo doméstico nessas propriedades. Nesta revisão, a primeira seção enfatiza o conteúdo de nutrientes em frutas e vegetais, compostos bioativos funcionais e bioacessibilidade e a modificação induzida

pela produção pós-colheita e / ou sistema de armazenamento, a variedade e o estado fisiológico do vegetal. Uma segunda seção trata das frutas e verduras produzidas no Uruguai, mostrando pesquisas recentes realizadas no país. E uma terceira seção versa sobre as perspectivas de aplicação em políticas públicas e políticas de promoção aos consumidores desse marcador especial de saúde associado aos alimentos vegetais.

Palavras-chave: vegetais, nutrição, saúde humana, sistemas de produção, processamento

1. Introduction

The evolution of the human being, in its individual and sociocultural dimension, has been accompanied by the incorporation of diverse food sources that have made it possible to provide all the essential nutrients for life, allowing cognitive and skill development[1][2][3]. Access to vegetables, fruits, flowers, seeds, tubers, roots, stems and leaves has provided valuable nutrients[4] and compounds with multiple properties for the benefit of good health and anti-aging[5]. Recently, new approaches are the subject of intense research, relating fruit and vegetable consumption to a lower state of stress, which affects individuals' social life[6]. The daily intake of fruits and vegetables contributes to a favorable dietary pattern that supports the requirements of macro and micro essential nutrients[7] and provides compounds that affect different physiological and structural functions, whose diversity is equivalent to the biodiversity of the plant kingdom itself[8]. Bioactive compounds, also called phytochemicals or phytonutrients, do not have nutritional value in terms of macro and micronutrients, nor in essential nutrients, but they are necessary to maintain a state of good health[8][9][10].

Knowledge of fruit and vegetable contribution of essential nutrients and bioactive compounds to human diet creates a unique opportunity to promote public policies of appropriate consumption, as well as policies that guarantee the right to food and social access, that stimulate their production, processing innovation and conservation technologies at different scales. Based on the knowledge of its value as food, public policies should promote the consumption of fruit and vegetables in children, teenagers and older individuals, above all, since these age categories are more sensitive to the lack of these valuable foods in their diets.

2. Nutritional value of fruit and vegetables

2.1 Content and bioavailability of nutrients in fruit and vegetables

Fruit and vegetables are components of the human diet that, depending on the food and the group to which they belong, are sources of various nutrients. Some foods stand out because they provide carbohydrates (potatoes, sweet potatoes, pumpkins); proteins (legumes); vitamin A (carrots, squash, sweet potatoes, peaches, melons), B vitamins (leafy vegetables), vitamin C (citrus, kiwi, broccoli), dietary fiber; macro and microminerals and a variety of bioactive compounds[8][11][12][13]. We will refer to essential nutrients such as vitamin A and C, and to a group of very important macronutrients such as carbohydrates, which are mainly provided by tubers, some roots and fruit[14][15][16][17]. Particularly, carotenoids are the precursors of vitamin A and, like vitamin C (ascorbic acid, L-ascorbic and L-dehydroascorbic), they are obtained from food; fruit and vegetables can contribute up to 75 to 95% of the total daily requirements[14][15][16][17]. Carotenoids are found in yellow, orange and red fruits and vegetables[13][18]. More than 700 carotenoids have been identified, and only 10% would have vitamin A activity; β-carotene has 100% provitamin A activity, α-carotene 50-54%, β-crytopxanthin 50-60%, and γ-carotene 50-52%[18][19][20][21]. However, studies that detect carotenoid forms and bioactivity in less usual fruit and vegetables or less attractive in color, are still scarce[17][20][21]. Other carotenoids such as zeaxanthin, lutein, lycopene, astaxanthin and violaxanthin are not provitamin A, and their bioactivity is related to photoprotection and antioxidation, maintaining the reduction-oxidation balance in living organisms[13][16][18]. The total carotenoid content in fruit and vegetables is <1 to 850 mg g^{-1} fresh

vegetable weight[18][20], presenting high variation in carotene and xanthophyll content according to species, variety, maturity state[20][22][23][24], production and/or conservation conditions[20][21][23], and form of preparation after harvest[16][17][21][25][26]. Vitamin C, essential and necessary for multiple functions, is contained in different forms and amounts in green vegetables and fruit[14][15]. The biggest challenge regarding vitamin C forms is access to fresh versus processed vegetables and the potential losses of this important soluble vitamin[14][17]. Another aspect is the content of vitamin C in vegetables such as potatoes, vegetables of American origin, whose diversity is not yet fully studied although it is the basis of many diets, mostly in fragile socio-economic contexts[15][27][28].

Regarding the carbohydrates in vegetables that are part of the food base of many countries and also Uruguay[27][28][29], such as sweet potatoes, potatoes, pumpkins and others, their interest lies in the alterations of their starch fraction from harvest to storage. Previous studies have shown that the bioavailability of glucose, the final product of starch degradation, is modified with storage time, variety and cooking[16][29]. This knowledge related to the carbohydrate content of each vegetable impacts the diet of people with glucose intolerance whose levels are very important to modulate[29][30]. Bioaccessibility and bioavailability studies are less numerous than content studies[12][16][20][22][24][29]. However, they indicate how much is available for absorption at the intestinal level[16][19][22][24][25]. It is highlighted that the bioavailability of a key nutrient within a vegetable depends on the structure, changes caused by maturity, processing and storage, as well as preparation[16][19][21][23][26]. For example, for carotenoids, bioaccessibility is lower in lycopene than in β-carotene, lutein and phytofluen[19]. Other bioactive compounds of interest, although not nutrients, as they are found in plants, are very low[12][23]. The simpler polyphenols, with low molecular weight, can be absorbed in the small intestine, while the more complex ones reach the colon without alterations[31]. From the total polyphenols contained in food, only 5 to 15% are bioaccessible[12][30]. The rest of the polyphenols are metabolized into simpler phenolic compounds by the microbiota of the large intestine[31]; the effects have been scarcely studied[12][13].

The number of nutrients and bioactive compounds present in plant matrices, which are naturally complex due to their anatomical structure, will present differences in the bioavailability of the nutrients housed therein, which implies the need for further studies[12][19][31].

2.2 The impact of processing and preservation on the nutritional value of fruit and vegetables

The processing or preparation of fruit and vegetables, whether minimal processing and/or cooking, or processes involving dehydration or high temperatures, as well as storage or shelf preservation, can positively or negatively modify the nutritional value, both in terms of content and bioaccessibility[12][14][21][24]. For example, water-soluble and thermolabile compounds such as vitamin C and various polyphenols present losses when cooked in an aqueous medium[17]. They frequently lose their bioactivity due to high temperatures, exposure to UV rays, air, or contact with other pro-oxidant elements[14][17].

On the other hand, interesting nutritionally valuable changes have been observed during refrigerated preservation processes (14°C, 75%RH) and traditional structures without temperature control, such as the increase of carotenoids in ripe and whole winter squash fruits (*Cucurbita moschata*, *Cucurbita maxima* x *Cucurbita moschata*)[16][25][32][33][34][35]. This increase was not observed in all varieties of sweet potato (*Ipomoea sweet potato* L.), a reserve root[32]. Another factor that alters the amount of β-carotene extracted is the decrease of the particle, as a result of homogenization in carrots (*Daucus carota* L.) and squash[26]. The type of variety and the way of cooking influenced this response in both carrots and squash[16][23][31].

The nutrient content of each type of fruit and vegetable will depend on the variety, maturity, time and form of harvest, the type of preservation and storage, as well as the way of processing, affecting their quantity and bioavailability, and thus generating a constant need for research, especially in local varieties, or native fruits and vegetables whose information is relevant[35].

3. Bioactive compounds in fruit and vegetables, and health effects

The botanical diversity of plants is associated with a variety of phytochemical compounds with multiple health effects through mechanisms associated with nerve, immunological, intestinal, and free radical functions at cellular level. The variety of phytochemicals ensures high exposure to these when ingesting plant-based foods[8][9]. Some of these important effects that characterize phytochemicals will be briefly emphasized.

3.1 Antioxidant effect

The metabolism that allows maintaining our lives is permanently exchanging electrons between molecules product of oxidation-reduction reactions. Different reactive oxygen species (ROS) are formed in these processes, among them free radicals and other compounds with a short half-life (10^{-5} s to $^{-9}$ s) and high reactivity[35][36][37]. If these ROS are accumulated, they react with amino acids, oxidize residues of guanine constituent of RNA and DNA, they break proteins, inactivate enzymes and generate lipid oxidative breakdown. All these processes damage cellular structure, permeability and functioning[37][38][39][40], triggering aging and different types of degenerative diseases that will be mentioned below[6][7][36][41][42]. Fruits and vegetables are the main source of a wide compound diversity, many easily bioavailable, that would counteract the ERO, maintaining the balance of the cellular system. These compounds include vitamin C, carotenoids and phenolic compounds. Vitamin C can donate hydrogen to an oxidizing system naturalizing the presence of free radicals, such as superoxide anion ($O_2^{\bullet-}$), hydroxyl ($OH^{\bullet}$), hydrogen peroxide (H_2O_2), reactive nitrogen species ($NO_2^{\bullet}$) and singlet oxygen ($^1O_2$)[36][43]. Vitamin C also intervenes by regenerating α-tocopherol (vitamin E) and consequently restoring its antioxidant activity[36][43]. Vitamin C benefits are related to the reduction of lipid peroxidation and uric acid in the blood, and it reduces the incidence of cardiac arrest and degenerative diseases[36][42][43]. For their part, carotenoids are very efficient in suppressing singlet oxygen ($^1O_2$) and triplet ($^3O_2$), and to a lesser extent than vitamin C and polyphenols, they inactivate free radicals[37][38][40][43]. In addition, they can reduce electronically photoexcited molecules, due to their carbon chain molecular structure (C_{40}) with conjugated double bonds, buffering the impact of free electrons that are triggered by the effect of UV light[37][39][43]. Wide beneficial effects on human health are described by the effect of carotenoids[36][38][40][42][43]. Among them, some xanthophylls such as lutein, zeaxanthin and astaxanthin stand out, which act as photoprotectors on the skin and retina, while present in fruit and vegetables in very small amounts (0.1 to 30 µg 100^{-1}g)[43][44][45]. It is worth noting that, along with the beneficial effects of carotenoids, they can act as pro-oxidants in very high concentrations (> 30 mg β-carotene day^{-1})[45][46].

Phenolic compounds are other components with high antioxidant capacity identified in more than 10,000 plant species as products of secondary metabolism[9][29][37][38][43]. According to the molecule complexity, phenols are classified into phenolic acids, flavonoids, stilbenes, coumarins, lignans and tannins[9][47], with the majority being in the first two groups. Given the diversity of chemical structures, the antioxidant capacity differs according to the number of hydroxyl groups, among others, and the main antioxidant mechanism is free radicals sequestration[37][47]. Polyphenols reduce low-density lipoprotein oxidation, proliferation of cancer cells, and reduce DNA damage in intestinal mucosa cells by 21%[11][36][48].

3.2 Anti-inflammation effect

The most important non-communicable chronic diseases, such as obesity, type 2 diabetes, cardiovascular diseases, heart attack and cancer, account for more than 60% of global mortality each year[41]. The pathogenesis of these diseases seems to be associated with the processes of chronic inflammation[49][50], and this would be linked to unhealthy dietary habits, excess or nutritional deficiency, deteriorating the immune system[50][51]. In recent years and particularly in this pandemic period, a healthy diet would contribute to reducing risk factors and consequent complications from infections and would improve the immune response to pathogenic microorganisms[50][51]. At the same time, efforts to prevent and control these pathologies by promoting diets and nutrition, have evolved from a simple

nutrient focus to a dietary pattern focus, which is strongly associated with patterns that include fruits and vegetables[52]. The dietary pattern rich in fruits and vegetables has been associated with optimal functioning of the intestinal microbiota, allowing the body to cope with infections and inflammatory states[8][43][51].

3.3 Effects on cognitive function

Cognitive aptitude has a strong impact on children's performance, particularly in learning, just as cognitive impairment affects older individuals and their independent development[53]. Recent studies show a strong association between fruit and vegetable consumption and a decreased risk of cognitive impairment[54]. In particular, lutein and astaxanthin present in vegetables would be the compounds related to brain health in healthy older adults[55]. Recent studies have shown an association between stress and consumption of fruits and vegetables[6][56], which would impact behavior in society.

4. Nutritional and functional value of fruit and vegetables produced in Uruguay

More than 70 botanical species of fruit and vegetables are produced and marketed in Uruguay[57], including roots, tubers, inflorescences, fruits, stems, leaves and seeds. Some are local varieties selected and/or improved by producers and research centers[57][58] focusing on increasing productivity and/or storage capacity. Furthermore, native species with edible fruits[59] have been prospected, selected and disseminated, which could increase the supply of this type of food with differentiated nutritional value. For the vast majority of fruits and vegetables produced and consumed in Uruguay, there is little information on the nutritional value and/or bioactive compounds of interest with an integrative approach to the production process, storage and even the forms of consumption.

Some studies carried out in sweet potato and winter squash, two of the most consumed vegetables in Uruguay[57], report that for every 100 g of cooked pulp the intake is 0.2 to 7 times, 3 to 7% and 22 to 49% of the daily requirement of provitamin A, carbohydrates and vitamin C for an adult, respectively[32]. At the same time, the intake of these vegetables provides other non-provitamin carotenoids (lutein), where only 40 to 70% of the total glucose is bioaccessible, and they vary according to species, variety and time of storage[32]. In the country's mandarins, grapefruits and feijoa fruits, the vitamin C content per 100 g of fresh weight would contribute 40 to 62% of the daily requirements of an adult[25][60]. On the other hand, national studies evaluating the total antioxidant capacity and the total polyphenol content in fruits and vegetables have increased, without differentiating chemical groups or species. Among the studied fruits, native species with a high content of vitamin C and antioxidant compounds stand out[60].

5. Actions that contribute to the promotion of consumption and the application of public policies

The acquired knowledge provides the necessary scientific evidence that relates the daily consumption of appropriate and abundant amounts of fruit and vegetables to a lower risk of diseases that negatively affect people's life quality, whether they are children, adults, or seniors. On the other hand, the loss of cognitive functions is less noticeable, impacting on the individual performance, but also at a social level, affecting emotional balance and exposing to states of stress or depression, limiting the ability to adapt to different situations. Two types of interventions are proposed to promote consumption and to apply public policies:

a- Strategies based on university education programs

Studies published on the promotion of consumption through education and university outreach programs[61] aimed at children and teenagers have contributed to understanding and adopting consumer behavior in different countries and cultures[62] with a positive impact[63]. These studies are based on the fact that schools provide a relevant and equitable environment to stimulate and increase vegetable consumption, based on the development of food preferences and learning from sensory experiences[63]. Complementarily, other studies are

directed to the elderly and urban population with a similar strategy in education, extension and interventions using horticulture and/or gardens in collective spaces[64][65][66]. This strategy must be addressed quickly in Uruguay since it has an aging population (15% over 64 years) that is expected to increase in the short to medium term (30 years); at the same time that this age group has a dietary pattern today that is not appropriate for healthy aging[64][65]. The individual-vegetable garden interaction, in this age group, would contribute to the life quality in terms of nutrition, but also associating physical activity, and emotional and social aspects. Its implementation promotes therapeutic strategies that mitigate the adverse effects of aging in the elderly and at the same time promote healthy aging[66][67][68].

b- Strategies based on the application of public policies

Aiming to reduce the prevalence of chronic non-communicable diseases, public policies applied in low- and middle-income countries focused on increasing (57%) or promoting (75%) the intake of fruit and vegetables[69][70] following the WHO recommendations. However, the intake levels recommended by the WHO (two servings of fruits and three servings of vegetables per day for an adult) have not yet been reached, being the socioeconomic factor decisive in terms of access or purchase possibilities and in the dietary pattern that is configured in low-income families[1][2][70][71]. This relationship between fruit and vegetables accessibility and consumption has been demonstrated in the important PURE study published by Miller and others[72] carried out in low-income countries. Therefore, public policies must be reinvented to address the greatest factor affecting fruit and vegetable consumption, the socioeconomic.

Facilitating access to fruit and vegetables requires actions at different levels, which are set out below:

a- Promote fruit and vegetable consumption in children in educational centers.

b- Promote actions aimed at educating on the consumption of appropriate amounts.

c- Establish social policies that favor the incorporation of fruits and vegetables in the dietary patterns in all socioeconomic extracts of the population, with emphasis on the most vulnerable and with limited means.

d- Distribute equitably to places far from the production areas, improving local availability and accessibility of food.

e- Regulate and differentiate prices following the seasonal productive activity.

f- Value the species of fruits and vegetables produced locally and the native ones, focusing on the most vulnerable age groups through a socio-economic and cultural approach.

g- Educate on the concept that the attributes considered of quality in fruits and vegetables, such as shape, size, and color, do not indicate high nutritional quality, and that irregular shapes, small size or slight defects do not imply low nutritional quality ("*ugly fruit, too good to go*").

h- Innovate in the communication of the ways of preparing fruits and vegetables at the domestic level, emphasizing ease, low cost and the contribution to family health.

6. Conclusions

Uruguay is a fruit and vegetable producing country, which also has important native species and the challenge of developing policies and programs aimed at generating knowledge in a framework of productive sustainability and contribution to the health of the population.

Author contribution statement

All authors contributed equally to the elaboration of the article.

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