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Polyphenols and Flavonoids in Colombian Fruit and Vegetables - Applications and Benefits: A Review

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Abstract Fruits and vegetables are important sources of nutritional and therapeutic compounds. Polyphenols and flavonoids are plant secondary metabolites with several biological functions and multiple benefits for humans. Their general chemical characteristics, such as their structures and functional groups, are key to explain their variability and functionality. This review covers 21 Colombian fruits and vegetables containing different amount of polyphenols and flavonoids. They have several applications and offer various benefits, such as antioxidant, bactericidal, and anti-inflammatory activities. Nutritional contributions and therapeutic applications of polyphenols and flavonoids have been reported in multiple studies, and these phytochemicals can be incorporated into dietary products. It is feasible that further beneficial effects of these natural compounds may be discovered in fruits and vegetables found in several regions of Colombia.

Keywords: *chemical characteristics, biological action, nutritional benefits*

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1. Introduction

Flavonoids are the most numerous types of polyphenolic phytochemicals. They are found in different parts of the plant and display different biological functions, as well as contributing to the colour of the plant [1]. Polyphenol molecules comprise several classes, and flavonoids are the most studied. The subgroups of flavonoids include stilbenes for example resveratrol, anthocyanins such as apigeninidin, and phenolic acids like caffeic acid. Polyphenols and flavonoids have different biochemical actions [2]. Flavonoids are antioxidants, anti-inflammatory compounds, and fat reducing agents [3,4]. Although these phytochemicals have multiple health benefits, their mechanisms of action are not completely clear, mainly due to their structural variability [5].

Health effects of polyphenols have attracted the attention of nutritionists and health professionals. In 1995, it was rare to see the term "flavonoids" in non-specialist books [5]. The first International Conference on Polyphenols and Health took place late in 2004, with the participation of researchers from more than 30 countries. It focused on advances in the understanding of polyphenol intake, and its effects on disease and health [5]. This review aims to survey polyphenols and flavonoids in Tropical and Amazonian dietary products found in Colombia. One fruitful research direction is the comparison of polyphenols and flavonoids in well-studied dietary products such as strawberries, red wine, nuts, grapes, olive oil, and apples.

1.1. General Aspects

Polyphenols are a heterogeneous group of molecules that share structural characteristics — they all have substituted benzene groups with hydroxyl and other functional groups. Flavonoids are the best defined polyphenolic subgroup found in human diet [1]. Flavonoids are aromatic heterocyclic compounds containing oxygen pigments and are widely distributed in plants. Flavonoids are constituents of most yellow, red and blue colours in plants and fruits [6]. Their structures comprise two phenyl groups labelled as A and B, joined by a pyran group represented by the letter C. This cyclic structure forms a diphenylpyrane core expressed as C6-C3-C6 that is common to most flavonoids [1]. Figure 1 shows a general representation of a polyphenol with its functional groups.

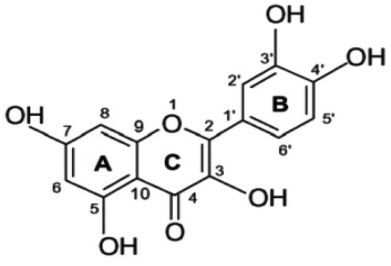

Figure 1. General chemical representation of a polyphenol

Oxygen functional groups provide polarity to aromatic rings, the water solubility increasing as the number of

oxygen substituents increases [7]. The functionality of polyphenols and flavonoids and their classification depends on functional groups present. Chemical groups found in polyphenols include hydroxyl, ketone, and carboxyl groups [8]. Most polyphenols in nature exist as glycosides which join to glucose or galactose. Within the flavonoid group, there are flavanol, flavone, flavanone, and anthocyanin subclasses [9].

1.2. Biochemical Processes

Polyphenols display pharmacological activities. They may act in vasodilation, as anticancer, anti-inflammatory, and bactericidal agents, as immune system stimulants, as antiallergenic, antiviral, and oestrogenic agents, and as lipoxygenase and xanthine oxidase inhibitors [10]. Epidemiological studies report that polyphenols may protect against bladder and lung cancer. There is also evidence that polyphenols are cardioprotective [10].

Several studies report that flavonoids have pro-oxidant activity [11,12,13]. They protect organisms and prevent damage to humans caused by oxidants such as UV radiation, environmental pollution, and chemical substances in food. [12]. It has been suggested that flavonoids are better antioxidants than vitamins, being efficient free radical regulators. This characteristic makes them beneficial in several nutritional and medical aspects [14,15,16]. Their free radical targets are hydroxyl and superoxide radicals, which are known to be very reactive in lipid peroxidation [13].

Flavonoids modify eicosanoid synthesis and prevent platelet aggregation, yielding antithrombotic effects and protecting low-density lipoproteins from becoming oxidized, thus preventing atheroma formation [13,15]. They also block tumour development and prevent angiogenesis, preventing the arrival of oxygen and nutrient at neo-tumour cells [17]. They also modulate oestrogenic reactions by attaching to receptors, lowering the risk of breast cancer. Several flavonoids can inhibit cytochrome P-450 dependent monooxygenases, playing a role in regulating the activation of carcinogens [17].

2. Colombian Products as Sources of Different Polyphenol Types

Multiple varieties of fruit grow in all regions of Colombia (South America) [18,19]. Different climates, geographical conditions, and water resources favour the cultivation and harvesting of local fruits and vegetables [19]. New studies are focusing on evaluating the biological activity of tropical and Amazonian fruits from Colombia.

The star fruit, or carambola, *Averrhoa carambola* (Oxalidaceae), develops in low and medium altitude tropical conditions (0-1,200 meters above sea level); it grows in several regions in Colombia (i.e. Valle del Cauca, Córdoba, Antioquia, Quindío, Tolima, Meta, and the Caribbean zone). Its optimum temperature is in the range 21 to 32°C [20]. The flesh of the carambola fruit is light yellow, crisp and juicy; its flavour varies from very acid to sweet. Apigenin is found in the pulp, and it exhibits anti-inflammatory and anti-tumour activities [21].

Zapote mamey (*Pouteria sapota*) originates from southern Mexico and northern Nicaragua. It can be found throughout Central America, the Caribbean, and northern South America. It is found at altitudes up to 1500 m. This fruit contains catechin and has high antioxidant activity [22]. One study has found an inverse relationship between the consumption of zapote mamey and the incidence of cardiovascular diseases and cancer [23].

Wild cocoa or copoazú (*Theobroma grandiflorum*), is an exotic tropical fruit found in Peru, Colombia, Ecuador, and Brazil. Copoazú is cultivated in regions with annual average temperatures above 22°C, rainfall above 1,500 mm, and relative humidity above 75% [4]. Catechin is the major flavonoid in copoazú, and it provides antioxidant effects [3]. More examples of polyphenol sources are shown in Table 1, highlighting their biological functionality.

Table 1. Polyphenol sources and some of their biological actions

#	Colombian source of polyphenols	Type or subclass	Biological action	Reference
1	Acaí *Euterpe oleracea*	Flavonoids	Anti-inflammatory	[24,25]
2	Albaricoque *Ximenia americana*	Flavonoids	Antioxidant	[26,27,28]
3	Berenjena *Solanum melongena*	Anthocyanin	Antioxidant	[29,30,31]
4	Borojó *Borojoa patinoi*	Phenols Flavonoids	Antioxidant Antimicrobial	[32,33]
5	Capulí *Prunus serótina*	Anthocyanin	Antioxidant	[34]
6	Chope *Gustavia augusta*	Flavonoids	Antioxidant	[35,36,37]
7	Chulupa *Passiflora maliformis*	Anthocyanin Flavonoids	Antioxidant Antimicrobial	[38]
8	Coriander *Coriandrum sativum*	Flavonoids	Antioxidant	[39,40]
9	Copaíba *Copaifera langsdorffii*	Flavonoids	Antimalarial Gastro protective	[41,42,43]
10	Curuba larga *Passiflora mollissima*	Flavonoids	Antioxidant	[44]
11	Strawberry *Fragaria vesca*	Flavonoids	Anti-inflammatory	[45,46]
12	Bean *Phaseolus vulgaris*	Anthocyanin	Antioxidant	[47,48]
13	Sour guava *Psidium araca*	Flavonoids	Antioxidant	[49,50]
14	Sugar mango *Mangifera indica*	Phenols	Antioxidant	[51,52,53]
15	Passion fruit *Passiflora edulis*	Phenols	Antioxidant	[54,55]
16	Blackberry *Rubus fruticosus*	Flavonoids	Anti-inflammatory	[56,57]
17	Tree tomato *Cyphomandra betacea*	Flavonoids	Antioxidant	[58,59]
18	Grapefruit *Citrus paradisi*	Flavonoids	Anti-inflammatory	[60,56]
19	Uchuva *Physalis peruviana*	Flavonoids	Antioxidant	[61,62,63,64,65]
20	Grape *Vitis vinifera*	Flavonoids	Antiansiolitic	[66,67]
21	Yacón *Smallanthus sonchifolius*	Flavonoids	Antidiabetic	[68,69]

3. Applications and Contributions to Health

3.1. Nutritional Aspects and Benefits

Polyphenols and flavonoids are found in fruit, vegetables, and other dietary products, such as wine, tea, chocolate, and coffee [2]. The types and contents consumed vary depending on source and its frequency of consumption. Regular coffee use in North America accounts for about 500-800 mg of hydroxycinnamic acid consumption per day [2]. Different studies show that total individual flavonoid intake, from different products, is up to 20 mg/day in the USA; while in the Netherlands, it can be higher than 70 mg/day [70,71,72,45].

The inclusion of the flavonoid catechin in the diet, consumed in dry seeds and tea, yields a 20% reduction in the incidence of disease [73]. In a study with around 5,000 volunteers given flavonoids from different foods including tea, the risk of myocardial infarction was inversely associated with flavonoid consumption [73,74]. Health benefits from polyphenol and flavonoid-rich diets are attributed mainly to their anti-obesity effects, and their antioxidant and anti-inflammatory activities [72].

Polyphenols act both directly and indirectly on adipose tissue, which interact specifically with pre-adipocytes, stem cells and immune system cells [72]. Catechins from green tea and flavonoids such as resveratrol and curcumin provide antioxidant and anti-inflammatory activities in obese individuals [72]. They offer health benefits, lowering body weight, cellular, and plasmatic lipids, and increasing the basal metabolic rate, energy expenditure, and insulin sensitivity [72]. A significant reduction in the incidence of coronary disease is associated with flavonoid consumption [75]; clinical studies suggest that prophylactic administration of these polyphenols reduces free radical production in reperfusion generated from bypass surgery in vascular replacement [12].

3.2. Therapeutic Uses

The antioxidant and anti-inflammatory actions of polyphenols and flavonoids have attracted attention for therapeutic use. An example of this is a study which evaluated flavonoids found in blackberries and strawberries against the action of anti-inflammatory drugs such as acetylsalicylic acid [45]. These flavonoids inhibited hyaluronidase, responsible for inflammatory processes [45]. Quercetin, a flavonoid with anti-inflammatory and antioxidant activities found in several fruits, decreases the expression of claudine-2 in A549 lung adenocarcinoma cells [76]. These studies show that potential therapeutic targets of flavonoids could offer beneficial alternative therapies.

Another therapeutic activity of flavonoids is found in extracts and seeds of grapefruit; they exhibit bacteriocidal, fungicidal, and antiviral activities as well as being effective against the HIV virus *in vitro* [56]. Naringenin, found in this fruit, inhibits the replication of dengue virus in human monocytes infected with serotype-4 [77]. Naringenin also inhibits enzymes related to cytochrome P450 and the development of breast cancer cells [78,79]. Naringenin is thus a potential natural drug with several therapeutic targets.

Acai is a flavonoid rich tropical fruit and its polyphenols are efficient regulators of inflammation in obesity, and also feasible modulators of low grade chronic inflammatory factors [24]. Consumption of acai pulp has been shown to accentuate the expression of epidermal growth factor and plasminogen activator inhibitor-1 (PAI-1) in overweight women, leading to higher expression of PAI-1 protein and improving insulin resistance. In this study, the women also reported lower blood pressure levels [24].

Olive oil and tomato are important sources of polyphenols. The inclusion of rich polyphenols in virgin olive oil and tomato has yielded positive effects on cardiovascular disease risk factors [80]. Consumption of tomato sauce enriched with refined olive oil decreased the total cholesterol in plasma. Triglycerides and various inflammatory cellular and plasma biomarkers were also diminished, while HDL cholesterol levels increased [80]. These polyphenols also increased the proportion of intestinal bacteria coated with immunoglobulin A (IgA) [80]. An enhancement of the activity of intestinal-associated lymphoid tissue was observed, IgA being the most abundant immunoglobulin in the intestinal mucosa (80-90%) and playing a very important role as the first defense against toxins and pathogen colonization and invasion [80].

Cacao, also called cocoa, is a flavanol rich product. It reduces vascular inflammation [81]. A brain imaging study showed that after the consumption of flavanol-rich cocoa there was an increase in cortical blood flow [81]. This result is of particular relevance when considering possible therapies to increase cerebrovascular function and to influence different brain regions for neurogenesis. Flavonoids in cocoa also increase cerebral blood flow and protect neurons against inflammatory processes that lead to cell injury [81].

Flavonoids in different dietary products offer anxiolytic or anticonvulsant effects; they can interact with gamma amino butyric acid (GABA) receptors and produce sedative action [82]. Studies have shown that quercetin and isoquercetin have anticonvulsive effects in experimental epilepsy models [82,83]. Research has demonstrated that flavonoids are able to exert antiepileptic activity by modulating the GABA receptor chloride ion channel, because they are structurally similar to benzodiazepines [83].

4. Discussion and Conclusion

The variety and functionality of polyphenols and flavonoids explains their multiple nutritional and therapeutic values to humans. Their functional groups and numerous subclasses allow them to participate in several biochemical pathways and to provide different biological activities [7,9]. One of the most studied properties of polyphenols and flavonoids is their antioxidant activity [1,5,6,18]. They also possess anti-inflammatory, antiviral, bactericidal and fungicidal activities. Colombian fruits and vegetables are a source of several polyphenols and flavonoids. A wider variety of tropical and Amazonian products could become important providers of these phytochemicals in the future.

Some polyphenols may provide alternatives to commonly used drugs. Several diseases are inhibited by specific flavonoids. These natural compounds have been used in the treatment of viruses, cancerous cells, and lipid disorders, and for the improvement of the nervous system and cerebrovascular functions [45,76,80,81]. Flavonoids, in comparison to commonly used drugs, can act at different points of biochemical pathways. New tropical and Amazonian fruits should be evaluated, focusing on their total polyphenol content in order to widen the possibilities for therapeutic alternatives for the treatment of current and future diseases.

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