

Genipap (Genipa americana L.): A Promising Natural Blue Pigmented Functional Food

Manjunatha S.¹; Shobha D.²; Nikhil R.³; Dinesh Ravi⁴; Divya C.⁵

^{1,3}Msc Scholar, Department of Food Science and Nutrition, College of Agriculture, University of Agricultural Sciences, GKVK, Bengaluru-560065, Karnataka, India.

²Professor, Department of Food Science and Nutrition, College of Agriculture, University of Agricultural Sciences, GKVK, Bengaluru-560065, Karnataka, India.

⁴Independent Scholar, Chennai, India

⁵Young Professional 2, AICRP on Women in Agriculture, UAS, GKVK, Banaglore-65

Publication Date: 2026/09/30

Abstract: Genipa americana L. (genipap) is a tropical fruit native to Central and South America, which has demonstrated potential to be a good functional food and natural pigment source for the food industry. The fruit is particularly rich in iridoids (mainly geniposide and genipin), phenolic compounds, flavonoids, carotenoids and dietary fiber. A characteristic biochemical property is the ability of the fruit to produce a stable natural blue pigment by enzymatic hydrolysis of geniposide to genipin, which then reacts with amino groups to give an intense blue color. This pigment is more stable than synthetic dyes and maintains >95% absorbance in pH 2-7, making it an attractive alternative to synthetic food colorants. Beside its use as a colorant, genipap exhibits a strong antioxidant, anti-inflammatory, antiproliferative, antiglycation and antimicrobial potential. Recent studies on human bioavailability support the functional potential of genipap as identifiable metabolites were found in human urine after its consumption. The fruit and the by-products from processing are used in beverages, dairy products, bakery goods and confectionery. On average about 40% of fruit mass is discarded during juice production. They are an important agro-industrial residue with a high valorization potential. Recent regulatory developments include FDA approval of Gardenia (Genipin) Blue as an exempt-from-certification color additive (July 2025) and its authorization by the EFSA with an acceptable daily intake (ADI) of 34 mg/kg body weight per day. However, industrial applications are hindered by optimizing pigment stability, standard extraction protocols, limited cultivation infrastructure, and clinical validation, among others, despite the tremendous commercial potential. This review summarizes the current scientific knowledge of Genipa americana as a multifunctional natural food ingredient, with emphasis on its botany, nutritional composition, phytochemistry, mechanisms of formation of natural blue pigment, biological activities, applications in the food industry, regulatory status, and future prospects.

Keywords: Genipa americana, Genipap, Genipin, Geniposide, Natural Blue Pigment, Functional Food, Iridoids, Antioxidants, Food Colourant, Regulatory Approval, Bioavailability.

How to Cite: Manjunatha S.; Shobha D.; Nikhil R.; Dinesh Ravi; Divya C. (2026) Genipap (Genipa americana L.): A Promising Natural Blue Pigmented Functional Food. *International Journal of Innovative Science and Research Technology*, 11(9), 1885-1895. <https://doi.org/10.38124/ijisrt/26sep944>

I. INTRODUCTION

The global food industry is experiencing a paradigm shift toward natural food ingredients due to increasing consumer awareness of potential negative health effects of synthetic food additives and colorants. This change is supported by the increasing strictness of the regulations governing the use of artificial dyes in food products in developed countries. Natural pigments from plant sources have attracted considerable attention from both scientific and industrial perspectives, not only due to their coloring capacity but also due to the simultaneous nutritional and functional health benefits (Neri-Numa et al., 2020).

Genipa americana L., or genipap or jenipapo, is a particularly promising candidate among underutilized tropical fruits for the development of functional foods. Native to Central and South America, with Brazil as the main center of genetic diversity and commercial cultivation, genipap has been used for centuries by indigenous communities as food and medicine. It is often used to make fruit juices, jams, wines, syrups, liquors and fermented beverages. The pigment has been traditionally used for body painting and for dyeing textiles. Genipap has been recently subjected to scientific studies that systematically characterized its extensive nutritional composition and abundance of phytochemicals, which support its

classification as a functional food with great commercial potential (Bentes and Mercadante, 2014).

The nutritional and functional value of genipap is associated with its remarkable content of bioactive compounds, especially iridoids of the monoterpenoid class of secondary metabolites. The main iridoids, geniposide and genipin are the main bioactive ingredients, which confer the characteristic biological activities of the fruit, as well as its unique capacity to generate a stable natural blue pigment. The glycosidic form, geniposide, is usually present in immature fruits and is enzymatically hydrolyzed to genipin, the aglycone form. This form then undergoes cross-linking reactions with primary amino groups present in amino acids, peptides and proteins (Bentes and Mercadante, 2014). This biochemical cascade results in the formation of complex nitrogenous polymers that are intensely blue in color. Unlike anthocyanin-based natural pigments, which are known to be highly unstable under pH variations and environmental perturbances, genipin-derived blue pigments present excellent color stability, retaining >95% of their absorbance across the pH range of 2–7 (Neri-Numa et al., 2020).

Beside its coloring properties, *in vitro*, *in vivo* (animal) and emerging human studies have shown that genipap has potent antioxidant, anti-inflammatory, antiproliferative and antiglycation activities mediated by synergistic interactions between its iridoid and phenolic constituents. Recent metabolomic studies in humans have unambiguously confirmed the bioavailability of compounds derived from genipap, with the presence of characteristic metabolites (genipic acid, genipic acid glucuronide and 3(7)-dehydrogenipinic acid) in human urine after the intake of genipap juice (Dickson et al., 2020). The results provide strong evidence for the functional efficacy of genipap consumption and support the development of its application as a functional food and nutraceutical ingredient.

The sustainability aspect of using genipap further increases the valorization of genipap. The history of fruit processing operations has resulted in large quantities of peel and seed residues being discarded as waste (approximately 40% of the total fruit mass in juice production). Nevertheless, recent studies have shown that these processing by-products have similar or higher concentrations of bioactive compounds than the fresh pulp, and thus they are valuable raw materials for industrial applications in functional foods, nutraceuticals, pharmaceuticals and cosmetic formulations (Gualberto et al., 2021). This ability to utilize the whole fruit contributes to the principles of the circular bioeconomy and enhances the economic sustainability of genipap supply chains.

Nevertheless, the commercial exploitation of *Genipa americana* is still constrained by some technical and scientific challenges. Recent regulatory developments give cause for encouragement. *Gardenia* (Genipin) Blue was approved as an exempt-from-certification color additive by the U.S. In July 2025, the Food and Drug Administration (FDA) approved the use of jagua as a food additive (under 21 CFR Part 73) and determined that it is safe to use in a

variety of foods at levels consistent with good manufacturing practice (FDA, 2025). The European Food Safety Authority (EFSA) also performed a risk assessment for jagua (genipin-glycine) blue and set an acceptable daily intake (ADI) of 34 mg/kg body weight per day based on a 12-month toxicity study (EFSA, 2024). The estimated dietary exposure was below the ADI at the proposed maximum use levels of up to 5,000 mg/kg food (EFSA, 2024).

The major limitations for wider commercial use are: (a) increased stability of the native blue pigment under food processing and storage conditions; (b) development of standardized scalable extraction technologies with consistent product quality; (c) development of cultivation infrastructure outside Brazil; and (d) additional human clinical data to support health claims, beyond demonstrating bioavailability. Overcoming these limitations will be important to help shift genipap from an underutilized tropical curiosity to a commercially relevant natural ingredient for the global food industry.

This review compiles the current scientific knowledge on the botany, nutritional composition, phytochemical profile, mechanisms of natural formation of blue pigments, reported biological activities, applications in the food industry, regulatory status, processing technologies, by-product valorization strategies and future development prospects of *Genipa americana* L., a multifunctional natural food ingredient with great commercial and nutritional potential.

II. ORIGIN AND DISTRIBUTION

Genipa americana L. is a perennial tree species of the Rubiaceae family, native of the tropical and subtropical regions of Central and South America. The species has a broad geographical distribution from southern Mexico thru Central America to northern and central South America, including Brazil, Colombia, Venezuela, Peru, Ecuador, Bolivia, Paraguay and Caribbean islands (Bentes and Mercadante, 2014). Brazil is the major center of genetic diversity and commercial production, where the species is cultivated and consumed widely in fresh and processed forms. The species is naturally found colonizing various ecological niches such as Amazonian rainforests, Atlantic forests, riverbanks, wetlands and seasonally flooded floodplains, exhibiting a great ecological plasticity and adaptation to humid tropical ecosystems.

Genipap is best grown in tropical and subtropical climates, with an annual average temperature of 22 to 30 degrees Celsius and an annual rainfall of more than 1200 mm. The species is most productive on deep fertile well-drained soils but is tolerant of seasonally flooded areas and a range of soil types. Although commercial production is still largely confined to Brazil, the demand for natural food colorants and functional ingredients is increasing interest in the introduction of genipap to other tropical countries. In India, genipap cultivation is at the experimental stage and is

confined to botanical gardens and research institutions in tropical areas with suitable climatic conditions.

➤ Botanical Characteristics

Genipa americana L. is an evergreen perennial tree. It usually reaches a height of 8–14 m but can be more than 20 m tall under suitable environmental conditions. The tree has a straight cylindrical trunk with smooth gray to brown bark and forms a broad dense canopy of many branches. The strong root system helps to tolerate periodically flooded soils and also helps to adapt to humid tropical ecosystems (Bentes and Mercadante, 2014).

The leaves are simple, opposite, oblong to elliptic, dark green and glossy, some 20 to 35 cm long and 8 to 15 cm wide. It has veins and smooth margins, and looks nice all year round.

The flowers are bisexual, tubular, fragrant, creamy white to pale yellow. Flowering typically occurs in the rainy season, and fruit development takes place over a period of months. Insects, especially bees, are the main pollinators, but other pollinators can also contribute to the establishment of fruit.

The fruit is a fleshy berry, round to oval in shape and weighs about 150–300 g, according to genotype and growing conditions. The fruit is mature and has a thick greenish-brown skin with soft aromatic juicy flesh and many flattened brown seeds. During ripening the peel turns from green to brown and the pulp softens and develops a characteristic sweet aroma. The fruit averages about 63 mm in transverse diameter and about 73 mm in longitudinal diameter, but considerable variation exists among cultivars and production environments.

Genipap is distinguished by a botanical trait, the high levels of iridoid glycosides, in particular geniposide, in its unripe fruits (Bentes and Mercadante, 2014). Geniposide is converted to genipin by tissue damage or enzymatic hydrolysis, which reacts with amino compounds to form a characteristic blue pigment. This biochemical characteristic is found only in genipap and is not found in most other tropical fruits and this has drawn a great deal of industrial interest in the production of natural food color.

➤ Nutritional Composition of *Genipa americana* L.

Genipa americana L. is a tropical fruit with appreciable amounts of macronutrients and micronutrients that contribute to its nutritional quality and functional properties. Genipap is widely recognized as a rich source of health-

promoting compounds that can be used in value-added products, tho its chemical composition varies depending on the cultivar, the maturation stage and environmental conditions (Neri-Numa et al., 2020).

The genipap pulp has a high moisture content (70–85%) which gives a soft texture and juiciness. The major macronutrient is carbohydrates with reducing sugars approximately 9.4% and nonreducing sugars 4.5%. This contributes the characteristic sweet taste and is an important energy source with the fruit supplying approximately 43–92 kcal per 100 g fresh weight (Dickson et al., 2020). The protein content is generally between 0.5 and 3.2 g per 100 g fresh pulp, whereas the lipid concentration is fairly low (0–1.6 g per 100 g), which makes genipap a natural low-fat fruit. Moreover, the endocarp has higher protein contents than the mesocarp, with the endocarp having 3.19% protein content compared to the mesocarp with 0.62%, favoring efficient pigment production in the endocarp (Bentes et al., 2015).

Another important nutritional component is dietary fiber and the amount of dietary fiber in genipap is about 4.64 g/100 g fresh weight, which is associated with improved gastrointestinal health, delayed glucose absorption, enhanced satiety and reduced risk of chronic metabolic disorders. Peel and seed fractions also show higher levels of insoluble dietary fiber, which are promising raw materials for functional food ingredients.

Genipap also contains essential micronutrients such as calcium (458.44 mg/100 g), iron (15.94 mg/100 g) and phosphorus (18–37 mg/100 g), which are involved in bone development, hemoglobin synthesis and energy metabolism, respectively (Neri-Numa et al., 2020). The fruit is rich in vitamins A, C and E and B-complex vitamins. The vitamin C content varies widely with the maturity of the fruit, from 1.1 mg to 33 mg/100 g fresh weight. The genipap has a high amount of carotenoids, with about 874.49 mg per 100 g of fresh weight (Neri-Numa et al., 2020).

Genipap is loaded with phytochemicals such as iridoids, phenolic acids, flavonoids and anthocyanins, in addition to the conventional nutrients. These compounds are responsible for the functional properties of the fruit that show high antioxidant, anti-inflammatory and antimicrobial activities. These compounds are usually found in higher concentrations in unripe fruits, especially the iridoids geniposide and genipin, which are important precursors for the formation of natural blue pigment (Bentes and Mercadante, 2014).

Table 1 Nutritional Composition of *Genipa americana* L. Fruit (Per 100 g Fresh Weight)

Component	Amount
Moisture	70–85 g
Carbohydrates (total)	4.4–25.7 g
Reducing sugars	~9.4%
Nonreducing sugars	~4.5%
Protein	0.5–3.2 g
Fat	0–1.6 g
Dietary fibre	~4.64 g

Energy	43–92 kcal
Calcium	85–458 mg
Iron	1.1–15.94 mg
Phosphorus	18–37 mg
Vitamin C	1.1–33 mg
Carotenoids	~874.49 mg
Thiamine (Vitamin B ₁)	0.08–0.17 mg
Riboflavin (Vitamin B ₂)	0.18–0.37 mg

Source: Adapted from Neri-Numa et al. (2020), Bentes and Mercadante (2014), Dickson et al. (2020), and Bentes et al. (2015).

III. BIOACTIVE COMPOUNDS OF GENIPA AMERICANA L.

Genipa americana is a rich source of bioactive phytochemicals that contribute to its nutritional and industrial value. These compounds are found in the pulp, peel, and seeds, and their levels vary based on fruit maturity, genotype, and environmental conditions (Neri-Numa et al., 2020). The main biologically active components are iridoids, phenolic compounds, flavonoids, carotenoids and anthocyanins, which together confer antioxidant, anti-inflammatory, antimicrobial, antiproliferative and natural coloring properties.

➤ Iridoids

Iridoids are the main bioactive compounds in genipap and belong to the class of secondary metabolites known as monoterpenoids. The major iridoids in the fruit include geniposide, genipin, geniposidic acid and genipin-1- β -gentiobioside (Neri-Numa et al., 2020). Among them, geniposide is the most abundant compound in immature fruits, which accounts for >70% of the total iridoids, and is the precursor of genipin by enzymatic hydrolysis (Bentes and Mercadante, 2014). Quantitative analysis demonstrated that the unripe genipap fruit contained 60.77 mg/g fresh dry weight of genipin, which was the most abundant iridoid in the unripe fruit, while the ripe genipap fruit contained 89.48 mg/g fresh dry weight of geniposide and 25.04 mg/g fresh dry weight of geniposidic acid (Neri-Numa et al., 2020). Total iridoid content decreases >90% during ripening, explaining the lack of blue pigment formation in ripe fruits after tissue damage (Bentes and Mercadante, 2014).

Beside pigment formation, iridoids have been reported to possess various biological activities like antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, neuroprotective and anticancer activities. It was found that genipin inhibited the NF- κ B signaling pathway, inhibiting inflammatory mediators and reducing oxidative stress and inflammatory responses. Genipin also showed significant antiglycation activity by inhibiting the formation of

advanced glycation end product (AGE), which may be helpful in the management of diabetes-related complications (Santos et al., 2023).

➤ Phenolic Compounds

Another important group of phytochemicals in genipap are phenolic compounds. Major phenolics reported are chlorogenic acid (5-caffeoylquinic acid), derivatives of caffeic acid, feruloyl and p-coumaroyl (Bentes and Mercadante, 2014). These compounds are important for protecting plant tissues against oxidative damage and contribute to the antioxidant capacity of the fruit. Phenolic compounds are effective scavengers of reactive oxygen species (ROS), inhibitors of lipid peroxidation and reduce cellular oxidative stress. Generally, their concentration is higher in unripe fruits, but it decreases gradually during ripening due to metabolic transformations (Bentes and Mercadante, 2014).

➤ Flavonoids

Genipap has high amounts of flavonoids like quercetin and kaempferol and their glycosidic derivatives (Neri-Numa et al., 2020). Flavonoids are well established for their antioxidant and anti-inflammatory activities as hydrogen donors and free radical scavengers. Beside their antioxidant functions flavonoids are reported to modulate multiple cellular signaling pathways including those involved in inflammation, apoptosis and immune responses.

➤ Carotenoids

Another large class of pigments found in genipap are the carotenoids. Studies have demonstrated that genipap has 874.49 mg of carotenoids/100 g fresh weight (Neri-Numa et al., 2020). The major carotenoids are β -carotene and lycopene. These compounds act as effective antioxidants by quenching singlet oxygen and scavenging free radicals generated during oxidative metabolism. β -Carotene is also a precursor of vitamin A, and therefore it contributes to visual function, immune competence and maintenance of epithelial tissues.

Table 2 Major Bioactive Compounds of *Genipa americana* L. and their Biological Functions

Bioactive Group	Major Compounds	Major Biological Functions
Iridoids	Geniposide, Genipin, Geniposidic acid	Blue pigment formation, antioxidant, anti-inflammatory, antimicrobial, antiglycation
Phenolic compounds	Chlorogenic acid, Caffeic acid, Ferulic acid derivatives	Antioxidant, free radical scavenging, anti-inflammatory
Flavonoids	Quercetin, Kaempferol	Antioxidant, anticancer, cardioprotective, anti-inflammatory
Carotenoids	β -Carotene, Lycopene	Antioxidant, provitamin A activity, immune support

Anthocyanins	Cyanidin derivatives	Antioxidant, cellular protection, cardiovascular health
--------------	----------------------	---

Source: Adapted from Neri-Numa et al. (2020), Bentes and Mercadante (2014), and Santos et al. (2023).

IV. MECHANISM OF NATURAL BLUE PIGMENT FORMATION IN GENIPA AMERICANA L.

MECHANISMS OF FORMATION OF NATURAL BLUE PIGMENT IN GENIPA AMERICANA L. The phenomenon of formation of a stable natural blue pigment by the plant *Genipa americana*, involving the conversion of geniposide to genipin and its reaction with amino compounds is described. The blue pigment derived from genipap is more stable than blue pigments derived from anthocyanins, which are highly sensitive to pH and environmental conditions. Thus, it is an attractive natural alternative to synthetic blue food colorants (Bentes and Mercadante, 2014). The growing consumer demand for clean label products has also driven research on genipap-derived pigments for food, pharmaceutical and cosmetic applications.

➤ *Geniposide: The Natural Precursor*

Geniposide is the main iridoid glycoside found in the immature fruits of genipap. Chemically it is an iridoid aglycone attached to a glucose molecule via a glycosidic bond. Endogenous β -glucosidase enzymes hydrolyze geniposide and cleave the glucose moiety during fruit processing or tissue disruption, producing genipin, the active aglycone responsible for pigment formation (Bentes and Mercadante, 2014). The content of geniposide in immature fruits is much higher than that in fully ripe fruits, so the immature fruits are the preferred raw material for the commercial extraction of natural blue pigments.

➤ *Formation of Genipin and Pigment Development*

Geniposide is enzymatically or chemically hydrolyzed under appropriate processing conditions. The resulting genipin is a highly reactive iridoid compound, which can react with primary amino groups of amino acids, peptides and proteins. Following formation genipin quickly reacts with free amino groups thru nucleophilic addition reactions. Further oxidation and polymerization yields complex nitrogen containing polymers of an intense blue color. The pigment gradually develops from light blue to dark blue depending on the reaction time, amino acid concentration and environmental conditions (Bentes and Mercadante, 2014). Anthocyanins, the blue pigment derived from

genipin, are very water soluble and relatively less stable under moderate processing conditions. This makes it especially suitable for use in beverages, dairy products, confections and bakery applications.

➤ *Factors Influencing Pigment Formation and Stability*

A number of environmental and processing factors influence pigment formation and stability:

- **Fruit maturity:** Immature fruits have the highest concentrations of geniposide and therefore higher yields of pigments (Bentes and Mercadante, 2014).
- **pH:** Neutral to slightly alkaline conditions favor pigmentation while strongly acidic conditions reduce the efficiency of the reaction. Genipin-derived pigments retained >95% of their absorbance in the pH range 2–7 (Neri-Numa et al., 2020).
- **Temperature:** Polymerization is controlled at moderate temperatures (20–40 °C), while excessive heating (above 80 °C) causes pigment darkening and can accelerate degradation.
- **Amino acid availability:** Amino acids that readily react with genipin, resulting in increased pigment formation and color intensity include lysine, glycine and especially glutamic acid. Studies on enzyme-assisted extraction show that the maximum recovery of genipin (196 mg/g) from genipap is achieved with Celluclast 10% at 36°C and pH 3.7 (Bellé et al., 2018).
- **Oxygen exposure:** Controlled oxidation is necessary for polymerization but prolonged exposure may slowly reduce pigment stability.
- **Light:** Prolonged exposure to light may cause reduction of color intensity, which makes the appropriate packaging systems necessary.

➤ *Comparison with Synthetic Food Colourants*

The blue pigment from genipap has several advantages over synthetic food dyes. It is derived from renewable plant resources, of low toxicity, has inherent antioxidant activity and meets the consumer demand for natural ingredients. Moreover, genipin-derived pigments are biodegradable and eco-friendly, offering a promising alternative to synthetic colorants such as Brilliant Blue FCF (FD&C Blue No. 1) (Neri-Numa et al., 2020).

Table 3 Steps Involved in Natural Blue Pigment Formation from *Genipa americana* L.

Step	Process	Product Formed
1	Geniposide present in unripe fruit	Geniposide
2	β -Glucosidase hydrolysis	Genipin + Glucose
3	Reaction of genipin with amino groups (e.g., glutamic acid, lysine)	Intermediate nitrogen-containing complexes
4	Oxidation and polymerization	Stable blue pigment (light blue to dark blue)
5	Food application	Natural blue food colourant (pH stable across 2-7)

Source: Adapted from Bentes and Mercadante (2014) and Bellé et al. (2018).

V. BIOLOGICAL ACTIVITIES AND HEALTH BENEFITS OF GENIPA AMERICANA L.

Genipa americana has received much attention because of its biological activities, which are related to its high content of iridoids, phenolic compounds, flavonoids and carotenoids. These bioactive constituents act synergistically to impart antioxidant, anti-inflammatory, antiproliferative, antiglycation, antimicrobial and other pharmacological properties. Recent studies show promising potential for chronic disease prevention and management, thus supporting the use of it as a functional food and nutraceutical ingredient.

➤ Antioxidant Activity

Oxidative stress caused by overproduction of reactive oxygen species (ROS) is a major contributor to cardiovascular diseases, diabetes, neurodegenerative disorders and cancer. Genipap is rich in antioxidants, thanks to the presence of iridoids, phenolic acids, flavonoids, and carotenoids that are capable to scavenge free radicals and inhibit oxidative damage (Neri-Numa et al., 2020). In vitro studies confirm the antioxidant potential of genipap extracts by DPPH, ABTS, ORAC and TEAC essays. These bioactive compounds are capable of inhibiting lipid peroxidation, protecting cellular macromolecules against oxidative damage and enhancing the endogenous antioxidant defense mechanisms. Unripe fruits exhibit particularly high antioxidant capacity because of the high concentration of iridoids and phenolic compounds (Bentes and Mercadante, 2014).

➤ Anti-inflammatory Activity

Chronic inflammation has been associated with several metabolic disorders, such as obesity, diabetes, cardiovascular diseases, and cancer. The anti-inflammatory effects attributed to genipin and other iridoids are related to their ability to modulate inflammatory signaling pathways. These compounds strongly inhibit lipopolysaccharide (LPS)-induced inflammatory responses by downregulating the expression of inflammatory cytokines, including tumor necrosis factor- α (TNF- α), interleukin-1 β (IL-1 β), interleukin-6 (IL-6), and inducible nitric oxide synthase (iNOS). Genipin inhibits the activation of NF- κ B signaling pathway, which reduces oxidative stress and the production of inflammatory mediators. The results point to the potential value of iridoids from genipap as natural anti-inflammatory agents for use in functional foods and therapeutic purposes.

➤ Antiproliferative and Anticancer Activity

The experimental data showed that genipap has potent antiproliferative activity against a variety of cancer cells. The main contributors to the biological effects are genipin and phenolic compounds that regulate cell proliferation, apoptosis and oxidative stress (Neri-Numa et al., 2020). Genipap extracts have shown ability to inhibit proliferation

of human tumor cell lines and also have high antioxidant activity. Genipin, an anticancer phytochemical has shown potential as an agent capable of inducing programmed cell death, inhibiting tumor growth and modulating multiple signaling pathways associated with carcinogenesis. Although the current evidence is mainly derived from in vitro and experimental studies, these results show a great potential of genipap as a source of natural anticancer compounds.

➤ Antiglycation Activity

Advanced glycation end products (AGEs) are formed by non-enzymatic reactions of reducing sugars with proteins and are implicated in the pathogenesis of diabetic complications, aging and cardiovascular disease. Genipin was effective in inhibiting AGE formation and destroying preformed AGE cross-links (Santos et al., 2023). Genipin showed significantly higher antiglycation activity compared to the other compounds in the protein-glucose glycation models, suggesting its ability to reduce glycation-related tissue damage. Antiglycation activity of genipin points to potential uses in preventing and managing diabetes associated complications and age related disorders.

➤ Antimicrobial Activity

Several studies have reported antimicrobial effects of genipap extracts against bacteria and fungi. Iridoids, flavonoids and phenolic compounds disrupt the microbial cell membranes, interfere with enzyme systems and inhibit the growth of microbes. Genipap showed inhibition against several foodborne pathogenic microorganisms, but the antimicrobial activity was different depending on the extraction method and solvent used. This property improves its application as a natural preservative and functional food ingredient (Neri-Numa et al., 2020).

➤ Human Bioavailability and Metabolite Evidence

Evidence Verification of bioavailability in human subjects is a crucial step in establishing the functional significance of genipap. Dickson et al. (2020) conducted a metabolomic analysis with sixteen healthy adult males who consumed genipap juice (250 mL) twice daily for three weeks and identified thirty-one urinary metabolites that were statistically altered. Most of these metabolites were linked to iridoids, medium-chain fatty acids, and polyphenols. Major urinary biomarkers were genipic acid, genipic acid glucuronide, 3(7)-dehydrogenipinic acid, dihydrocaffeic acid (DHCA), 1-(4-hydroxyphenyl)-1,2-propanediol and 3-carboxy-4-methyl-5-propyl-2-furanpropionic acid. The results confirm that bioactive compounds from genipap are absorbed, metabolized and excreted by humans, and provide scientific evidence for the consumption of genipap as a functional beverage (Dickson et al., 2020).

Table 4 Biological Activities of Major Bioactive Compounds Present in Genipa americana L.

Bioactive Compound	Biological Activity	Reported Mechanism
Genipin	Anti-inflammatory	Inhibits NF- κ B pathway; reduces IL-1 β , IL-6, TNF- α , iNOS
Geniposide	Antioxidant	Free radical scavenging and oxidative stress reduction
Phenolic compounds	Antioxidant	Neutralization of ROS and inhibition of lipid peroxidation

Flavonoids	Antiproliferative	Modulation of apoptosis and cell signalling pathways
Genipin	Antiglycation	Inhibits AGE formation and disrupts AGE cross-links
Carotenoids	Antioxidant	Quenching of singlet oxygen and free radicals
Iridoids (geniposide/genipin)	Bioavailable	Produces urinary metabolites (genipic acid, glucuronide conjugates)

Source: Adapted from Neri-Numa et al. (2020), Santos et al. (2023), and Dickson et al. (2020).

VI. EXTRACTION TECHNOLOGIES AND PROCESSING METHODS

Bioactive compounds and natural blue pigments extraction from genipap is important for commercial viability. Several extraction technologies have been evaluated to improve yield, purity and retention of functional properties.

➤ *Pressurized Ethanol Extraction*

Pressurized ethanol extraction is a very effective extraction method for genipap iridoids and phenolic compounds. The technique consists of organic solvent extraction at high pressure and temperature to improve mass transfer kinetics. Studies have shown that pressurized ethanol extraction produces high concentration of geniposide and other iridoids with antioxidant activity (Náthia-Neves et al., 2017). The isolated compounds exhibited DPPH and ABTS scavenging capacity, serving as evidence of the functional integrity of the recovered bioactives.

➤ *Enzyme-Assisted Extraction*

Enzyme-assisted extraction is recognized as a promising green technology for genipin recovery. Bellé et al. (2018) reported that the enzyme-assisted extraction of genipin from genipap pulp was carried out using Celluclast 10% in a liquid-liquid two-phase aqueous system at 36°C and pH 3.7, with a genipin yield of 196 mg/g. This environmentally friendly method does not involve the use of organic solvents and thus reduces the cost of processing and maintains the function of genipin for use as a natural food colorant or protein crosslinker. Hydrogels for enzyme immobilization were efficiently prepared by using the isolated genipin to crosslink chitosan with potential application in food processing (Bellé et al., 2018).

➤ *Ultrasound-Assisted Extraction*

Cold recovery of genipin from genipap fruit peel was found to be efficient by ultrasound-assisted extraction (UAE). The maximum yield of non-cross linked genipin 7.85 ± 0.33 mg/g was obtained at 10 °C for 15 min using ultrasound-assisted extraction coupled with enzymatic pre-treatment with pectinesterase as indicated by the research. The mechanical extraction together with ultrasound and enzymatic treatment caused an increase of eight times in the pigment yield due to the formation of polyelectrolyte complexes between pectic polysaccharides and proteins (Ramos-de-la-Peña et al., 2014). The low temperature extraction process preserves heat sensitive bioactive compounds and yields colorant-free extracts for food applications.

➤ *Standardization and Yield Optimization*

The extraction technology has improved but there is a wide variation in published procedures and thus the yield and quality of pigment is inconsistent. Optimization studies reveal that efficiency of extraction is dependent on enzyme type, enzyme concentration, extraction temperature, pH and substrate to liquid ratio and duration. In the future, standardized protocols will need to be developed to consistently produce high-quality genipap-derived ingredients at industrial scale.

VII. REGULATORY STATUS AND SAFETY EVALUATION

Recent regulatory developments are a major milestone for commercial deployment of genipin-derived colorants, eliminating previous uncertainty over regulatory approval pathways.

➤ *FDA Approval (United States)*

Gardenia (Genipin) Blue was officially approved by the U.S. Food and Drug Administration (FDA) as an exempt-from-certification color additive in July 2025 21 CFR Part 73 (FDA, 2025). In this regulatory context, manufacturers are authorized to use genipin-based colorants without the need for the rigorous certification processes that synthetic dyes must undergo. The FDA's safety determination was based on toxicological data included in a color additive petition that showed no genotoxicity and no adverse effects at appropriate levels of exposure. This is the fourth natural color additive approved by the FDA in recent months and is indicative of growing regulatory acceptance of plant-derived colorants.

➤ *EFSA Authorization (European Union)*

A comprehensive risk assessment has been carried out on jagua (genipin-glycine) blue as a food additive by the European Food Safety Authority (EFSA) in accordance with Regulation (EC) No 1331/2008. In a 12-month toxicity study in rats with in utero exposure, EFSA established a no-observed adverse effect level (NOAEL) of 3 385 mg/kg body weight per day. EFSA set an acceptable daily intake (ADI) of 34 mg jagua (genipin-glycine) blue per kg body weight per day (or 12 mg blue polymer per kg body weight per day, based on a 36.4% blue polymer content) considering appropriate safety factors (EFSA, 2024). The estimated dietary exposure to jagua (genipin-glycine) blue at the proposed maximum use levels of up to 5 000 mg/kg food did not exceed the ADI for all population groups. The Panel concluded that the food additive was not genotoxic and there were no adverse effects observed in repeated dose toxicity studies.

➤ *Toxicological Properties*

In safety assessments, the toxicological profiles of genipin-based colorants have been demonstrated to be favorable. *In vitro* Caco-2 cell permeability testing showed low permeability of the blue polymer which restricted systemic absorption. Minor organ discoloration and green-colored urine were observed at high doses in repeated dose toxicity studies, consistent with metabolic processing and excretion with no adverse toxicological effects. Extensive testing did not show genotoxicity, supporting regulatory approval for use in foods.

➤ *ADI and Dietary Exposure Assessment*

Based on a 12-month study in rats, the FDA established an ADI of 2.3 mg/kg body weight per day for the polymer derived from genipin, using a safety factor of 500. Dietary exposure modeling based on National Health and Nutrition Examination Survey (NHANES) 2013-2016 data estimated maximum exposure of 37 mg/person/day at the 90th percentile in children aged 6-12 years and adolescents aged 13-18 years. This estimated exposure value of 37 mg/person/day is well below the FDA-derived ADI of 138 mg/person/day, providing a large margin of safety for proposed uses (FDA, 2025).

VIII. APPLICATIONS OF GENIPA AMERICANA L. IN THE FOOD INDUSTRY

The increasing demand for natural food ingredients has provided great opportunities for the commercial use of *Genipa americana* due to its distinctive nutritional composition, high content of bioactive compounds and capacity to produce a stable natural blue pigment. Genipap has emerged as one of the key raw materials for the development of functional foods, natural food colorants and value added food products apart from being a rich source of nutrients and phytochemicals. The fruit, peel and seeds have a great industrial potential as they can be processed into different food ingredients and at the same time promote sustainability thru by-product utilization.

➤ *Natural Food Colourant*

One of the most valuable uses of genipap is in the production of natural blue food color. The blue pigment obtained by reacting genipin with amino compounds has received great industrial attention, because of the extreme scarcity of naturally occurring blue pigments. The pigments obtained from genipap are biodegradable, non-toxic and consumer-friendly and, unlike synthetic dyes, can be used in clean-label food products (Neri-Numa et al., 2020). Genipin derived pigments in the presence of whey proteins or other amino acid sources maintain >95% absorbance over a pH range of 2-7, thus they are applicable to a wide range of food products requiring pH stability (Gualberto et al., 2021). Recent regulatory approvals from the FDA and EFSA provide clear routes to commercialization.

➤ *Beverages*

Genipap pulp is widely used in the production of fruit juices, nectar, syrups, wines, fermented beverages and alcoholic liquors. Genipap has a pleasant aroma,

characteristic flavor and attractive color making it a perfect ingredient for beverage formulation. These drinks not only enhance sensory quality, but also offer antioxidants, dietary fiber and bioactive compounds that benefit consumers' health. Recent metabolomic studies have demonstrated that the regular consumption of genipap juice results in the presence of iridoid metabolites in human urine, suggesting bioavailability of its functional compounds, and supporting its role as a functional beverage (Dickson et al, 2020).

➤ *Dairy Products*

Natural blue pigments from genipap have shown promising applications in dairy products such as yogurt, flavored milk, ice cream and frozen desserts. The pigment provides an attractive, natural blue color and at the same time antioxidant compounds. Genipap pigments can fulfill the increasing consumer demand for naturally colored dairy products as opposed to synthetic colorants. In addition, genipap extracts enhance the functional value of dairy products by incorporating phenolic compounds and iridoids with antioxidant properties (Neri-Numa et al., 2020).

➤ *Bakery and Confectionery Products*

The pigments from genipap can be added to bakery products such as cakes, cookies, and pastries and to confectionary products such as candies, chocolates, and chewing gums. The pigment is sufficiently stable under moderate processing conditions and offers an attractive natural color without the safety concerns of synthetic dyes. The fruit pulp is also used for the preparation of jams, jellies, marmalades and fruit preserves, owing to its desirable flavor, aroma and pectin content (Bentes and Mercadante, 2014).

➤ *Functional Foods and Nutraceuticals*

Genipap is recognized as an important functional food ingredient due to its high content in iridoids, flavonoids, phenolic compounds and carotenoids. These bioactive compounds possess antioxidant, anti-inflammatory, antiproliferative, and antiglycation activities, which can lower the risk of chronic diseases such as diabetes, cardiovascular diseases, and some types of cancer (Neri-Numa et al., 2020; Santos et al., 2023). Therefore, there is growing research on the incorporation of genipap extracts into dietary supplements, functional beverages, health foods and nutraceutical formulations.

➤ *Valorization of Processing By-Products*

In fruit processing, large amounts of peel and seed residues are generated and they are traditionally discarded as waste. In the juice production, about 40% of the total mass of the fruit is discarded, which corresponds to a great part of the agro-industrial residues with great valorization potential (Gualberto et al., 2021). Recent studies, however, have shown that these by-products are rich in dietary fiber, phenolic compounds, antioxidants and iridoids, thus they can be considered valuable raw materials for industrial applications. The isolated bioactive compounds can be used in functional food products, nutraceuticals, cosmetic preparations and pharmaceutical components. Valorization of these processing residues contributes to waste

minimization, environmental sustainability and improved

economic returns thru circular bioeconomy approaches.

Table 5 Major Food Industry Applications of *Genipa americana* L.

Product Category	Application	Major Advantages
Natural food colour	Blue pigment for beverages, dairy, bakery	pH stable (2-7), FDA/EFSA approved, bioavailable, non-toxic
Fruit beverages	Juice, nectar, wine, syrup, fermented products	Functional drink, antioxidant-rich, verified biomarkers
Dairy products	Yoghurt, ice cream, flavoured milk, frozen desserts	Natural colour, antioxidant enrichment, consumer appeal
Bakery products	Cakes, cookies, pastries, bread	Clean-label colouring, stable under baking conditions
Confectionery	Candy, chocolate, jelly, gum	Attractive natural blue colour, stability
Functional foods	Nutraceuticals, dietary supplements, health foods	Bioactive compounds with documented biological activities
By-products	Peel and seed extracts	Dietary fibre (4.64 g/100g), antioxidants, iridoids, waste valorization

Source: Adapted from Neri-Numa et al. (2020), Bentes and Mercadante (2014), and Gualberto et al. (2021).

IX. CHALLENGES, RESEARCH GAPS AND FUTURE PROSPECTS OF GENIPA AMERICANA L.

Despite its great nutritional, functional, and industrial potential, the commercial use of *Genipa americana* L. is limited by several technological, agronomic, and scientific challenges. Although several studies have shown the potential of genipap as a natural source of blue pigments and bioactive compounds, more studies are needed to allow its commercialization on a large scale. Overcoming these limitations will allow for the wider use of genipap in food, pharmaceutical, cosmetic and nutraceutical industries.

➤ *Pigment Stability During Processing and Storage*

Genipin-derived pigments are usually more stable than anthocyanins with absorbance >95% over pH 2–7, but prolonged exposure to high temperature (>80°C), oxygen, intense light and extreme pH conditions can lead to a decrease in color intensity and product quality (Bentes and Mercadante, 2014). Thus, it is necessary to optimize the extraction methods, encapsulation technologies (micro- and nanoencapsulation) and suitable packaging systems to improve the stability of the pigments during food processing and storage. Recent studies showed that the addition of amino acids like glutamic acid improved pigment formation and storage stability to a large extent, indicating promising opportunities for industrial optimization.

➤ *Limited Commercial Cultivation*

At present, commercial cultivation of genipap is mainly confined to Brazil and a few neighboring tropical countries. There are no large-scale orchards, improved cultivars and standardized cultivation packages. More information on crop improvement, pest and disease management, irrigation scheduling and post harvest handling is available. However, for expansion of cultivation to other tropical and subtropical areas including India, systematic evaluation of agro-climatic adaptability, propagation methods and suitable production technologies are required.

➤ *Lack of Standardized Processing Technologies*

There are significant variations in the published methods for the extraction of bioactive compounds and natural blue pigments from genipap. Inconsistent pigment yield and quality often arise from variations in the solvent composition, extraction temperature, reaction conditions and purification techniques. Future studies should focus on the development of standardized, eco-friendly, and economically viable technologies for extraction at industrial scale that will keep the biological activity of the extracted compounds. Standardization potential of enzyme-assisted extraction and ultrasound-assisted extraction.

➤ *Limited Additional Clinical Evidence*

One metabolomic study has conclusively confirmed bioavailability of genipap compounds in humans (Dickson et al., 2020) however human clinical trials assessing functional health benefits, absorption kinetics, metabolism, pharmacokinetics and long-term safety of bioactive compounds derived from genipap are extremely scarce. Health claims for pharmaceutical or nutraceutical uses outside the scope of established bioavailability must be supported by extensive clinical investigations.

➤ *Research Gaps and Future Research Priorities*

There has been important progress, but there are a number of key research gaps:

- Development of improved genipap cultivars with high pigment content, fruit yield and nutritional quality
- Complete assessment of agro-climatic suitability for growing in different geographical areas
- Evaluation of the long-term safety and chronic toxicity of purified genipin-derived pigments in regulatory toxicology models
- Study of bioavailability, absorption kinetics and metabolic pathways of iridoids in different human populations
- Standardization of post-harvest handling and storage technologies to maintain iridoid content and pigment stability

- Commercial-scale extraction and purification processes with uniformity of product quality and purity
- Development of nano- and microencapsulation technologies to improve the stability of pigments during food processing and storage
- Novel applications in biodegradable food packaging, edible coatings, active food systems, biofortification
- Study of cost-benefit analysis and life cycle assessment for industrial scale processing
- Cross---border regulatory harmonization to facilitate international trade

Meeting these research needs will help in the commercialization, consumer acceptance, and economic potential of products made from genipap.

➤ *Future Prospects and Development Opportunities*

The future of *Genipa americana* is very promising due to the rapidly growing global market of natural food colorants and functional ingredients. The recent approvals from the FDA and EFSA clear the path to market entry, decreasing uncertainty regarding regulatory status. Growing consumer demand for clean-label foods and tightening regulatory restrictions on synthetic additives are creating favorable opportunities for the commercialization of genipin-derived pigments.

The advances in biotechnology, green extraction technologies, nanotechnology and food processing are expected to improve pigment stability, extraction efficiency and product quality. In addition, the application of peel and seed by-products for recovery of dietary fiber, antioxidants and phenolic compounds is in line with circular bioeconomy principles and sustainable food processing.

Future collaborative research in plant breeding, food science, biotechnology, agricultural engineering and nutrition will contribute to the development of new functional foods, nutraceuticals, pharmaceuticals and cosmetic products from genipap. Therefore, *Genipa americana* has great potential to be one of the most important natural sources of blue food colorants and multi-functional bioactive ingredients for the global food industries.

X. CONCLUSION

Genipa americana L. is an underutilized tropical fruit of great nutritional, functional and industrial importance. The fruit is rich in iridoids (especially geniposide and genipin with concentrations of 60.77 mg/g in unripe fruits for genipin and 89.48 mg/g for geniposide in ripe fruits), phenolic compounds, flavonoids, carotenoids (874.49 mg/100g) and other phytochemicals which show strong antioxidant, anti-inflammatory, antiproliferative, antiglycation and antimicrobial activities. Geniposide and its hydrolysis product genipin are of particular interest among these compounds because of their role in the formation of a stable natural blue pigment (>95% absorbance over pH 2–7), which provides a promising alternative to synthetic food colorants such as Brilliant Blue FCF (FD&C Blue No. 1).

Recent regulatory developments mark a watershed moment for commercialization. Regulatory certainty for market expansion: FDA approval of Gardenia (Genipin) Blue as an exempt-from-certification color additive (July 2025) and EFSA establishment of an ADI of 34 mg/kg bw/day. The bioavailability of genipap-derived metabolites in human subjects provides scientific validation for functional food applications (Dickson et al., 2020).

Studies of human bioavailability and other scientific research have suggested possible applications of genipap in drinks, dairy products, bakery products, confectionary, nutraceuticals, pharmaceuticals and cosmetics. The detection of characteristic urinary metabolites (genipic acid, genipic acid glucuronide, 3(7)-dehydrogenipinic acid, DHCA, etc.) after intake of genipap juice is a strong evidence of functional efficacy of compounds from genipap. Also, the valorization of peel and seed by-products (about 40% of the fruit mass in the juice production) contributes to sustainable processing by enabling the recovery of dietary fiber (4.64 g/100g) and bioactive compounds, reinforcing circular bioeconomy principles.

These advantages and recent regulatory advances are hampered by challenges such as optimizing pigment stability during processing and long-term storage, developing and validating standardized extraction technologies, limited cultivation infrastructure outside of Brazil, and generating additional human clinical evidence beyond bioavailability demonstrations for therapeutic health claims, restricting commercialization at a large scale.

Future research should be aimed at: (1) crop improvement and extension of cultivation to tropical/subtropical areas with suitable agro-climatic conditions including India; (2) optimization and standardization of processing techniques for industrial scale-up; (3) improvement of pigment stability using encapsulation technologies and innovative packaging systems; (4) pharmacokinetic and bioavailability studies in larger human populations; (5) human clinical trials showing functional health benefits for specific disease prevention applications; and (6) development of regulatory approval pathways across different geographic markets and regulatory jurisdictions.

Overall, *Genipa americana* is a promising multifunctional functional food and natural blue pigment source with a great potential to meet the increasing global demand for safe, sustainable, and health-promoting food ingredients. Recent regulatory approvals have turned genipap from a speculative opportunity into a validated commercial ingredient with clear market pathways. Continuous R & D efforts will be needed in plant breeding, agricultural engineering, food science, biotechnology and clinical nutrition to help move genipap from being an underutilized tropical fruit to an ingredient of commercial importance in the world's food, pharmaceutical and cosmetic industries.

REFERENCES

- [1]. Bellé, A.S., Hackenhaar, C.R., Spolidoro, L.S., Rodrigues, E., Klein, M.P. and Hertz, P.F. (2018) 'Efficient enzyme-assisted extraction of genipin from genipap (Genipa americana L.) and its application as a crosslinker for chitosan gels', *Food Chemistry*, 246, pp. 266–274. doi: 10.1016/j.foodchem.2017.11.028.
- [2]. Bentes, A.S. and Mercadante, A.Z. (2014) 'Influence of the stage of ripeness on the composition of iridoids and phenolic compounds in genipap (Genipa americana L.)', *Journal of Agricultural and Food Chemistry*, 62(44), pp. 10800–10808. doi: 10.1021/jf503378k.
- [3]. Bentes, A.S., de Souza, H.A.L., Amaya-Farfan, J., Lopes, A.S. and de Faria, L.J.G. (2015) 'Influence of the composition of unripe genipap (Genipa americana L.) fruit on the formation of blue pigment', *Journal of Food Science and Technology*, 52(6), pp. 3919–3924. doi: 10.1007/s13197-014-1651-9.
- [4]. Dickson, L., Tenon, M., Svilar, L., Faça-Berthon, P., Martin, J.C., Rogez, H. and Vaillant, F. (2020) 'Genipap (Genipa americana L.) juice intake biomarkers after medium-term consumption', *Food Research International*, 137, pp. 109375. doi: 10.1016/j.foodres.2020.109375.
- [5]. EFSA (European Food Safety Authority) (2024) 'Scientific opinion on the safety of jagua (genipin-glycine) blue as a food additive', *EFSA Journal*, 22(Suppl 1), pp. e8769. doi: 10.2903/j.efsa.2024.8769.
- [6]. FDA (Food and Drug Administration) (2025) 'Listing of color additives exempt from certification; gardenia (genipin) blue', *Federal Register*, 90(138). Available at: <https://www.federalregister.gov/documents/2025/07/15/2025-13175/listing-of-color-additives-exempt-from-certification-gardenia-genipin-blue> (Accessed: August 2026).
- [7]. Gualberto, N.C., Oliveira, C.S., Nogueira, J.P., Jesus, M.S., Araujo, H.C.S., Rajan, M. and Narain, N. (2021) 'Bioactive compounds and antioxidant activities in the agro-industrial residues of acerola (Malpighia emarginata L.), guava (Psidium guajava L.), genipap (Genipa americana L.) and umbu (Spondias tuberosa L.) fruits assisted by ultrasonic or shaker extraction', *Food Research International*, 147, pp. 110538. doi: 10.1016/j.foodres.2021.110538.
- [8]. Náthia-Neves, G., Tarone, A.G., Martelli-Tosi, M., Maróstica Junior, M.R. and Meireles, M.A.A. (2017) 'Extraction of bioactive compounds from genipap (Genipa americana L.) by pressurized ethanol: Iridoids, phenolic content and antioxidant activity', *Food Research International*, 102, pp. 595–604. doi: 10.1016/j.foodres.2017.09.041.
- [9]. Neri-Numa, I.A., Pessôa, M.G., Arruda, H.S., Pereira, G.A., Paulino, B.N., Angolini, C.F.F., Ruiz, A.L.T.G. and Pastore, G.M. (2020) 'Genipap (Genipa americana L.) fruit extract as a source of antioxidant and antiproliferative iridoids', *Food Research International*, 134, pp. 109252. doi: 10.1016/j.foodres.2020.109252.
- [10]. Ramos-de-la-Peña, A.M., Renard, C.M.G.C., Wicker, L., Montañez, J.C., García-Cerda, L.A. and Contreras-Esquivel, J.C. (2014) 'Environmental friendly cold-mechanical/sonic enzymatic assisted extraction of genipin from genipap (Genipa americana)', *Ultrasonics Sonochemistry*, 21(1), pp. 43–49. doi: 10.1016/j.ultsonch.2013.06.013.
- [11]. Santos, A.C., Otsuka, F.A.M., Santos, R.B., Trindade, D.J. and Matos, H.R. (2023) 'Antiglycation potential and antioxidant activity of genipap (Genipa americana L.) in oxidative stress mediated by hydrogen peroxide on cell culture', *Natural Product Research*, 37(12), pp. 2065–2069. doi: 10.1080/14786419.2023.2193849.