Additive potential of Araças fruit extracts in sunscreens: a multidimensional study of the impact on SPF

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Abstract

Growing concern about the harmful effects of ultraviolet (UV) radiation has driven the development of safer, more effective, and sustainable sunscreens. This study evaluated the potential additives of ethanolic extracts from the fruits of five araça species from the Brazilian Atlantic Forest— Psidium cattleyanum var. lucidum; Psidium guineense ; Psidium acutangulum var. oblongatum; Psidium myrtoides ; and Eugenia stipitata —in cosmetic formulations containing ethylhexyl methoxycinnamate (EHMC), aiming to increase the Sun Protection Factor (SPF). The formulations were prepared with 1% of the extracts, and the SPF was determined by in vitro UV spectrophotometry . The resulting extracts showed a significant increase in the SPF of the sunscreens, with emphasis on P. guineense (30%), followed by P. acutangulum var. oblongatum and E. stipitata (28%), and P. cattleyanum var. Lucidum (20%). Phytochemical screening revealed the presence of flavonoids, phenolic acids, terpenes, and tannins, compounds associated with antioxidant, anti-inflammatory, whitening, photoprotective, and regenerative activities. Spectrophotometric data demonstrated that the ripening stage of the fruits influenced photoprotective efficacy, with extracts from green fruits demonstrating superior UVA/UVB absorption than ripe (yellow) fruits. The results indicate that araça fruit extracts have a synergistic action with conventional UV filters, allowing a minimum 40% reduction in the concentration of synthetic organic filters and a 60% cost savings on photoprotective formulations. Therefore, these araça extracts constitute promising multifunctional additives, aligned with the " safe-by-design " approach, integrating efficacy, safety, and sustainability in the development of new sunscreens.

1. Introduction

Concern about sun protection has its roots in ancient civilizations, such as Egypt, where natural substances such as rice and clay were used to minimize damage caused by sun exposure. It is now known that ultraviolet (UV) radiation is responsible for various skin damages, including photocarcinogenesis and photoaging (1) . This awareness has significantly boosted the global sun care market, valued at US$12.6 billion, with a projected consumption growth of 5.28% by 2025 (2) .

Modern photoprotectors are cosmetic formulations that use (incorporate) sunscreens capable of reflecting or scattering UV radiation (inorganic filters - TiO_2 and ZnO) or absorbing it (organic filters - para-aminobenzoic acid/PABA and its esters) UV radiation. (3, 4) The World Health Organization (WHO) recommends the use of broad-spectrum sunscreens, with a Sun Protection Factor (SPF) equal to or greater than 30, to ensure effective protection against UV-B (λ 280-315nm) and UV-A (λ 315-400nm) radiation (5).

SPF quantifies the effectiveness of a sunscreen in prolonging sun exposure without causing skin erythema. SPF can be determined by three main methods: 1) *in vivo method* , by the ratio of the minimum erythematous dose (MED) of protected skin exposed to controlled UV radiation compared to unprotected skin (6); 2) *in vitro* method , through spectrophotometry in the UV-B region (7,8), or; 3) through *in silico prediction,* using computational modeling(9).

Despite their proven effectiveness, the use of sunscreens may be associated with adverse effects (10). Skin hypersensitivity reactions have been reported for certain filters and additives, while some carriers have comedogenic potential (11). Furthermore, the systemic absorption of organic filters raises concerns about possible endocrine effects, including estrogenic and antiandrogenic activity (4). From an environmental perspective, sunscreen residues released into aquatic ecosystems have been implicated in coral bleaching and negative impacts on marine biota (12).

To mitigate these effects, the industry has adopted strategies such as prioritizing inorganic filters; formulating sunscreens with lightweight, non-comedogenic carriers; and eliminating potentially allergenic fragrances and preservatives (13). Furthermore, the development of "reef-safe" products has been a growing trend, focusing on technologies that reduce risks to both human health and the aquatic environment (14,15). In this context, the Safe and Sustainable-by-Design (SSdD) approach has gained relevance, proposing the development of effective, biodegradable, and environmentally sustainable sunscreen formulations (12,16).

Simultaneously, there is growing interest in incorporating natural compounds with photoprotective properties, rich in chromophore and/or phenolic structures, which can enhance the SPF of formulations (3,17). Several secondary metabolites have demonstrated this capacity, such as flavonoids (quercetin, rutin, apigenin, luteolin) (18), resveratrol, ferulic acid, turmeric, silymarin, carotenoids, propolis, and vegetable oils (17). In addition to their photoprotective action, these compounds (natural filters) have additive properties, such as antioxidant activity, neutralizing free radicals and mitigating inflammatory processes induced by UV radiation (19); anti-inflammatory effect (20); whitening activity (21); and regenerative activity (22).

Within Brazilian biodiversity, araçás — whose name derives from the Tupi-Guarani “ara´sa,” "ara" (sky); "aza" (eye), meaning “eyes of the sky” (23) — encompass several species, from distinct genera or even families, with globose, fleshy, crowned fruits, erect in shape, resembling eyes looking toward the sky (24). Despite the taxonomic diversity, these species share chemical characteristics, notably the presence of the same bioactive compounds, such as flavonoids, phenolic acids, terpenes, and tannins, which confer therapeutic properties, including antioxidant, anti-inflammatory, and photoprotective activities, making araças potential additives when incorporated into sunscreens ((25–27).

This study aims to evaluate the additive capacity of araça fruit extracts in cosmetic formulations with synthetic organic sunscreens, specifically regarding the increase in the Sun Protection Factor (SPF). The research was conducted at the Laboratory of the Center for Applied Research and Innovation (NPAI/PPGFARMA/UNEB) and aimed to verify whether the incorporation of these araça fruit extracts in photoprotective formulations with synthetic filters contributes to increased efficacy in protecting against UV radiation. This study is duly registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under code ACDD0D0.

2. Materials and Methods

2.1 - Plant Material

Five species of common araças in Brazil were selected: *Psidium cattleyanum* var. lucidum; *Psidium guineense* ; *Psidium myrtoides, Psidium acutangulum* var. oblongatum and *Eugenia stipitata* (**Figure 01**). The fruits were acquired in the Baixo Sul region of the Brazilian Atlantic Forest in Bahia (Brazil), and botanical identification was carried out with the support of the Alexandre Leal Costa Herbarium (ALCB/UFBA)

2.2 - Preparation and concentration of extracts

Samples of fresh, healthy fruits were initially cleaned, cut, and frozen at -40°C. The araça fruits were then freeze-dried until they reached constant weight. Araça fruit extracts were obtained by three consecutive ethanol maceration cycles (48 hours each) using the pulverized material. The fractions were combined, concentrated in a rotary evaporator at 40°C, 100 mbar, and 90 rpm, and stored refrigerated for subsequent analysis.

2.3 - Phytochemical Screening

Aliquots of the extracts were resuspended in ethanol and subjected to phytochemical screening according to the methodology proposed by Matos et al. (1997)(28). The objective was to qualitatively identify the presence of flavonoids, tannins, coumarins, triterpenes, steroids, phenolic compounds, saponins, alkaloids, and free anthraquinone. To evaluate the effect of ripening stage, fruit samples of some species at different ripening stages (yellow-ripe or green) were analyzed separately to verify differences in the phytochemical profile.

2.4 - Determination of Phenolic Compounds

The total phenolic compound content was determined by the Folin-Ciocalteu (29) colorimetric method, using gallic acid as a standard. The analytical curve was constructed with gallic acid concentrations (5, 10, 15, 20, and 30 ppm), with triplicate absorbance readings at 765 nm, resulting in the straight line equation y = 39.216x. The samples were prepared at 0.15 g/mL and analyzed in triplicate. The results were expressed in mg of gallic acid equivalents per gram of dry extract (mgAG.g $^{-1}$).

2.6 - Photoprotective Formulations

The formulations were developed based on the Non-Ionic Lotion II (oil-in-water emulsion - O/W) described in the National Formulary of the Brazilian Pharmacopoeia, with modifications (BRASIL, 2024). The aqueous and oily phases were heated and mixed under constant stirring (940 rpm) until cooling and forming a stable creamy emulsion. **Table 01** presents the composition of the photoprotective formulations, divided into different types of oil-in-water (O/W) creamy lotions, with aqueous and oily phases.

Table 01: Composition of photoprotective formulations

Substances*	C1	C2	C3	SPc	SPg	SPA	SEs
Aqueous Phase (Phase 1):							
Sodium Lauryl Sulfate	1%	1%	1%	1%	1%	1%	1%
Methylparaben	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%	0.15%
Disodium EDTA	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Propylene Glycol	1%	1%	1%	1%	1%	1%	1%
Aqua (Water)	qs ad	qs ad	qs ad	qs ad	qs ad	qs ad	qs ad
Oily Phase (Phase 2):							
Cetearyl Alcohol	9%	9%	9%	9%	9%	9%	9%
Propylparaben	0.05%	0.05%	0.05%	0.05%	0.05%	0.05%	0.05%
Isopropyl Myristate	2%	2%	2%	2%	2%	2%	2%
- Solar filters							
Homosalate	N/A	8%	N/A	N/A	N/A	N/A	N/A
Rthylhexul Methoxycinnamate - EHMC	N/A	N/A	7.5%	7.5%	7.5%	7.5%	7.5%
- Plant Extracts							
Psidium cattleyanum var. lucidum extract	N/A	N/A	N/A	1%	N/A	N/A	N/A
Psidium guineense Extract	N/A	N/A	N/A	N/A	1%	N/A	N/A
Psidium acutangulum var. oblongatum Extract	N/A	N/A	N/A	N/A	N/A	1%	N/A
Eugenia stipitata Extract	N/A	N/A	N/A	N/A	N/A	N/A	1%

*INCI, International Nomenclature of Cosmetic Ingredients; C1 - Control 01 (Base formulation without extracts or sunscreens); C2 - Control 02 (Formulation with synthetic sunscreens only); C3 - Control 03 (Formulation with vehicle only); SPc - Sunscreen with *P. cattleyanum* extract; SPg - Sunscreen with *P. guineense* extract; SPa - Sunscreen with *P. acutangulum* extract; SEs - Sunscreen with *E. stipitata* .

The formulations vary mainly in the inclusion of synthetic sunscreens, such as Homosalate and Ethylhexyl Methoxycinnamate (EHMC), as well as plant extracts from several araçá species (*Psidium cattleyanum, P. guineense, P. acutangulum,* and *Eugenia stipitata*). Formula C1 serves as a control, consisting only of the base, without filters or extracts; C2 contains only synthetic sunscreens 8% Homosalate, equivalent to SPF 4, to define the Correlation Factor (CF), while C3 is the Creamy Lotion containing 7.5% EHMC. The formulations with extracts consist of 7.5% EHMC and the respective extracts: 1 - SPc - Sunscreen with *P. cattleyanum* extract ; 2 - SPg - Sunscreen with *P. guineense extract; 3 - SPa - Sunscreen with P. acutangulum* extract ; 4 - SEs - Sunscreen with *E. stipitata extract* .(29)

In vitro Sun Protection Factor (SPF) increase test

The FPS was determined by UV spectrophotometry, according to the method of Mansur et al. (1986)(7). Readings were obtained between λ 290 nm and 320 nm, at an interval of λ5 nm, and calculations were performed according to **Equation 01**

$$FPS = CF \times \sum_{290nm}^{320nm} \times EE_{(\lambda)} \times i_{(\lambda)} \times abs_{(\lambda)}$$

Equation 01

where:

SPF - Sun Protection Factor

CF - Correction Factor (10.24, determined with 8% homosalate, equivalent to FPS = 4).

EE (λ) - Erythematogenic effect of UV radiation with wavelength λ.

i (λ) - Intensity of UVB radiation with wavelength λ.

abs (λ) - Absorbance of the sunscreen sample for wavelength λ.

The values of EE(λ) and I(λ) were used as proposed by Sayre et al (1997)(30), presented in **Table 02** , which defines the parameters of erythematous response and spectral intensity of UVB radiation.

Table 02 - Normalized product function in the calculation of the Sun Protection Factor (SPF)

Wavelength (λ nm)	EE(λ) xi(λ)
290	0.0150
295	0.0817
300	0.2874
305	0.3278
310	0.1864
315	0.1864
320	0.0180
Total	1,0000
Sayre et al (1997)	

The increase in SPF was evaluated by comparing the formulations containing only the Synthetic Organic Filter (Base Lotion + EHMC 7.5%) and those containing, additionally, Araça fruit extracts (Base Lotion + EHMC 7.5% + Araça Fruit Extracts 1%). This comparison allowed us to estimate the contribution of natural compounds to increased photoprotection.(29)

3. Results and Discussion

3.1 - Phytochemical Screening

Phytochemical screening of ethanolic extracts from the fruits of *P. cattleyanum* var. lucidum; *P. guineense* ; *P. myrtoides; P. acutangulum* var. oblongatum and *E. stipitata* revealed profiles rich in bioactive compounds (**Table 3**). The universal presence of flavonoids and tannins stood out, compounds described as frequent chemical markers in the genus (*Psidium/Eugenia*) and widely associated with antioxidant and anti-inflammatory activities.(31) The detection of anthraquinones was observed only in the extracts of *P. guineense* and *P. acutangulum* var. oblongatum, while alkaloids occurred in *P. cattleyanum* var. lucidum and *P. guineense* .

Table 03 - Phytochemical screening of Araças fruits .

	Guinean P.	*P. acutangulum var.* oblongatum	*P. cattleyanum var.* lucidum	*E.ugenia stipitata*	*P. myrtoides*
Anthraquinone	(+)	(+)	(-)	(-)	+
Flavonoids	(+)	(+)	(+)	(+)	.+
Saponins	(-)	(-)	(-)	(-)	+
Tannins	(+)	(+)	(+)	(+)	+
Coumarin	(-)	(-)	(-)	(-)	-
Alkaloids	(+)	(-)	(+)	(-)	+
Terpenoids	(+)	(+)	(+)	(-)	+
Steroids	(+)	(+)	(-)	(+)	-

The phytochemical composition showed significant variations according to ripening stage: immature (green) fruits exhibited steroids, compounds related to growth and cell wall integrity, while ripe (yellow) fruits exhibited a higher incidence of terpenoids, secondary metabolites involved in defense against pathogens and modulation of sensory attributes, such as aroma and flavor (32). This transition reflects changes in biosynthetic pathways during ripening (metabolic plasticity), which can directly impact the functional profile of the extracts—a point to consider when standardizing fruit selection.

Another important observation was the variation in the phytochemical profile according to the fruit ripening stage and their moisture content. Immature (green) araça fruits presented steroids and lower moisture content, while more mature (yellow) fruits presented terpenoids and higher moisture content. These changes are attributed to ripening, as discussed by Bhatla and Lal 2023.

Araça species have considerable taxonomic diversity, a search on the *DataPlamt platform* resulted in 25 araça species, distributed in 10 genera (*Terminalia, Bellucia* , *Campomanesia* , *Feijoa* , *Myrcia* , *Pimenta* , *Posoqueria* , *Tocoyena*) and four families (*Combretaceae* , *Melastomataceae* , *Myrtaceae* , *Rubiaceae*). Even though they are taxonomically distinct, they are strongly linked to metabolic conservation, possibly related to polyploidy, apomixis and high ecological plasticity (33).

This metabolic preservation favors the maintenance of bioactive compounds common among the studied species (**Figure 02**), such as flavonoids (kaempferol, myricetin, quercetin and catechin); phenolics (gallic acid and ascorbic acid); and terpenes/monoterpenes (germacrene B, globulol, geraniol, terpinen-4-ol, d-limonene, alpha-terpinene, beta-myrcene, beta-ocimene, beta-pinene and eugenol) (34–39).

The dermopharmaceutical relevance of these metabolites includes: 1-Antioxidant activity - neutralization of reactive oxygen species and mitigation of oxidative damage induced by UV radiation (35,36); 2.- Photoprotective action - selective absorption of UVB/UVA radiation by chromophoric structures, with dissipation of energy in the form of heat (17); 3- Whitening/antimelanogenic effect - inhibition of enzymes such as tyrosinase, favoring the uniformization of skin tone (41).; 4- Regenerative and healing properties - modulation of inflammation and stimulation of collagen and elastin synthesis (41)

These compounds give araçá fruit extracts a strategic functional versatility for innovative photoprotective formulations (26,29,42). Furthermore, the phytochemical tests proposed by Matos et al. (1997) can be incorporated as a quality standard in the testing of extracts to be used in photoprotective cosmetic formulations.

3.1.1 - Total Phenolic Compound Content

The quantification of total phenolic compounds in the ethanolic extracts revealed marked variations among the species evaluated (**Table 04**). The highest content was observed in *P. acutangulum* var. oblongatum (226.63 ± 21.37 mgAG/g), followed by *P. myrtoides* (222.92 ± 21.63 mgAG/g), P. cattleyanum var. lucidum – green (98.76 ± 14.28 mgAG/g), P. cattleyanum var. lucidum – yellow (79.71 ± 1.60 mgAG/g), *P. guineense* – yellow (63.36 ± 1.42 mgAG/g), E. stipitata (32.08 ± 2.23 mgAG/g) and *P. guineense* – green (24.31 ± 2.18 mgAG/g). These values reflect intrinsic variations in secondary metabolism, influenced by both genetics and environmental conditions.

Table 04 : Total Phenolic Compounds Content - FT

	Dry Mass (g)	Dry Extract (g)	FT in the sample (mgAG/g)	
P. guineense - Yellow	75.07	5.42	63.36	±1.42
P. guineense - Green	36,117	0.45	24.31	±2.18
P. cattleyanum Lucidum - Green	19,467	0.82	98.76	±14.28
P. cattleyanum Lucidum - Yellow	38,887	2.19	79.71	±1.60
P. acutangulum Oblongatum	58.24	6.53	226.63	±21.37
E. stipitata	85.09	2.62	32.08	±2.23
P. myrtoides	43.05	7.89	222.92	±21.63

In reviews on the genus *Psidium/Eugenia* (37,38,43), the phenolic content of *P. guineense fruits* varied between 0.18 and 54.34 mgAG.g $^{-1}$.; in *P. cattleyanum* , between 0.85 and 5.01 mgAG.g $^{-1}$. while in the case of *P. acutangulum* , a value of 12.79 mgAG.g $^{-1}$ was reportedin the whole pulp(34) , while *E. stipitata* presented 9.06 mgAG.g $^{-1}$ of total phenolics in the dry extract (44). These discrepancies can be attributed to methodological factors, such as type of solvent, extraction protocol and stage of ripening of the fruits at the time of collection. The breadth of these results reinforces the influence of environmental factors, such as seasonality and water regime, on the biosynthesis of phenolic compounds (45). Previous studies indicate higher concentrations in autumn and spring, with a moderate negative correlation with precipitation and a weak correlation with cloud cover and relative humidity (46), corroborating the need to consider environmental variables when planning comparative studies.

Correlating these data with the moisture contents shown in **Table 4**, it is observed that *P. acutangulum* Oblongatum, with 79.85% moisture content, has the highest phenolic compound content, while *E. stipitata* , with 91.04% moisture content, has the lowest. The other species, such as P. guineense and *P. cattleyanum* . Lucidum, with moisture contents of 74.34% and 74.66%, respectively, have intermediate levels of phenolic compounds. This suggests that, although moisture content influences the stability of bioactive compounds, it does not directly determine the total concentration of phenolic compounds. Other factors, such as chemical composition and ripening stage, also play an important role.

Phenolic compounds play a fundamental role as antioxidants (47), neutralizing reactive oxygen species (ROS) generated by UV radiation (17). This action prevents lipid peroxidation (26), DNA damage, and degradation of skin structural proteins (40). Among the main phenolics and flavonoids described for the four araça species studied, flavonoids such as apigenin hexoside (43), catechin and its derivatives (hexoside and dihexoside) (48), gallocatechin, luteolin, kaempferol, and quercetin (38) stand out; phenolic compounds such as gallic and caffeic acids (35,37); terpenes such as linalool, geraniol, germacrenes, pinenes; and tannins such as eugenitin (49).

Previous studies reinforce the antioxidant potential of these extracts. Biegelmeyer et al. (2011) reported, for *P. cattleyanum* , a high radical scavenging capacity by the TRAP method at low concentrations (<1 mcg/mL) (38). In another study on *P. guineense* , an IC50 was observed: 1.58 g/L for peroxyl radical, 4.0 g/L for peroxynitrite, with inhibition of 13%-18% in the DPPH assay, depending on the solvent (39); The aqueous extract of *P. acutangulum* reduced nitric oxide production by 13% at 50 μg/mL (Ramos et al., 2015); while *E. stipitata* showed an IC50 of 0.69 ± 0.23 μg/mL in the DPPH assay (50).

This significant diversity of antioxidant compounds not only contributes to increased SPF in cosmetic formulations but also enhances the multifunctional properties of araça extracts. These compounds act synergistically to protect against UV radiation damage while promoting cell regeneration, making araça extracts a promising option for innovative cosmetic formulations with a focus on SSbD.

3.2 - Absorption of Araça Fruit Extracts in the UVA/UVB bands

Analysis of the ultraviolet (UV) radiation absorption capacity of ethanolic extracts from araçá fruit species demonstrated significant variations in photoprotective efficacy against UVA and UVB radiation, as indicated by the area under the curve (AUC) in the UVA (320-400 nm) and UVB (290-320 nm) regions. These data, presented in **Figure 03** , reflect the photoprotective potential of each extract.

Psidium guineense - Green extract showed a UVA/UVB ratio of 1.57, indicating a good balance of protection against both types of radiation. This suggests that these extracts offer effective protection against both sunburn (UVB) and photoaging (UVA). In comparison, *Psidium guineense* - Yellow had a

UVA/UVB ratio of 1.49 (**Figure 3**), indicating greater emphasis on protection against photoaging but less efficacy against sunburn.

Psidium *cattleyanum* Lucidum - Green demonstrated good absorption capacity, with a total AUC of 66.43 (**Figure 03**). Absorption in the UVA region (AUC_UVA = 37.18) was significant, while in the UVB region (AUC_UVB = 29.25) it was also significant, with a UVA/UVB ratio of 1.27. However, extracts from yellow fruits, such as *Psidium cattleyanum Lucidum* - Yellow, showed inferior performance, with a total AUC of 24.78. The reduced absorption (AUC_UVA = 14.92 and AUC_UVB = 9.86) suggests that fruit ripening decreases their UV absorption capacity, with lower photoprotective efficacy.

The Psidium acutangulum var. Oblongatum extract had a total AUC of 46.05, with good UVA absorption (AUC_UVA = 26.65) and moderate UVB absorption (AUC_UVB = 19.4), with a UVA/UVB ratio of 1.37 (**Figure 03**). This profile suggests that the protection offered by this extract is more focused on photoaging, with less defense capacity against sunburn.

Similarly, *E. stipitata extract* showed a total AUC of 44.62, with good absorption in the UVA region (AUC_UVA = 28.85) and lower absorption in the UVB region (AUC_UVB = 15.77). The UVA/UVB ratio of 1.83 (**Figure 03**) suggests that*E. stipitata* extract offers more focused protection against photoaging, but less effectiveness against sunburn, when compared with *Psidium* extracts , which have a more balanced UV absorption.

Psidium myrtoides extract presented the lowest UV absorption values, with a total AUC of 14.87 (AUC_UVA = 8.90 and AUC_UVB = 5.97), reflecting limited efficacy in protecting against sun damage. The UVA/UVB ratio of 1.49 (**Figure 03**) indicates that this extract primarily offers protection against photoaging, with a reduced capacity to absorb UV radiation, especially in the UVB range.

Although *Psidium guineense* - Green showed balanced UV absorption, extracts from yellow fruits, such as *P. cattaleyanum* Lucidum - Yellow, showed reduced absorption, resulting in less photoprotective effect. This suggests that fruit ripeness directly impacts UV protection efficacy, with green guava fruits exhibiting greater photoprotective potential.

The results indicate that fruit ripeness directly influences the composition of the extracts, with green fruits exhibiting greater photoprotective potential compared to ripe (yellow) fruits. These findings suggest that selecting extracts from green fruits is crucial for more effective natural photoprotective formulations. Furthermore, the phytochemistry of green species shows significant differences compared to yellow ones, with increased presence of terpenes, steroids, and increased moisture content—important indicators of quality and photoprotective efficacy.

3.3 - Evaluation of the increase of Araça Fruit Extracts in FPS

The SPF of formulations containing araçá fruit extracts was determined by UV spectrophotometry, following the method of Mansur et al. (1986). The results, presented in **Table 5** , demonstrated that all formulations with plant extracts showed a significant increase in SPF compared to Control Formulation

3 (C3), composed exclusively of the synthetic filter ethylhexyl methoxycinnamate (EHMC 7.5%). The increase in SPF ranged from 20% to 32%, with emphasis on *Psidium guineense* , which showed a 32% increase in SPF, from 25 to 33 SPF.

Table 5: Impact of araça extracts on increasing SPF and reducing synthetic UV filters

Component	**FPS**				
Control (C3): 7.5% EHMC	25				
Filters with Extracts:		**Increment (%)**	**Synthetic Filter Equivalent***	**Filter Reduction**	**Cost Savings**
P. guineense + 7.5% EHMC	33	32	7.5% EHMC+3.5% EHDP | 7.5% EHMC+12% Homosalate	31.8% | 61.5%	60.4% | 93.2%
P. acutangulum + 7.5% EHMC	32	28	7.5% EHMC +3.4% EHDP | 7.5% EHMC + 11.5% Homosalate	30.9% | 59.0%	59.7% | 92.9%
E. stipitata +7.5% EHMC	32	28	7.5% EHMC +3.4% EHDP | 7.5% EHMC+11.5% Homosalate	30.9% | 59.0%	59.7% | 92.9%
P. cattleyanum + 7.5% EHMC	30	20	7.5% EHMC+ 2.5% EHDP | 7.5% EHMC+ 8.2% Homosalate	22.7% | 42.0%	52.1% | 90.0%

SPF - Sun Protection Factor; EHDP - Ethylhexyl Dimethyl PABA; EHMC - Ethylhexyl Methoxycinnamate; *Data from simulation in Sunscreen Optimizer (https://www.sunscreen-optimizer.com/)

The photoprotective increase observed in photoprotective formulations with araçá extracts is attributed to the bioactive compounds present in the extracts, including flavonoids (apigenin hexoside and luteolin) (Beltrame et al, 2021), phenolic acids (methylcaffeoylquinic, caffeoylquinic and caffeoyltartaric acids) (Santos-Sánchez et al, 2019; Bezerra et al, 2018) and terpenes (alpha terpinene, luteolin and linalool and eugenol) (Pereira et al, 2019; Santos et al, 2023). These molecules have conjugated aromatic rings and hydroxyl groups that allow the absorption of UV-B and UV-A radiation (Mota et al, 2019; Stevanato et al, 2014), through electronic transitions (HOMO-LUMO) followed by the dissipation of the absorbed energy in the form of heat (Gonzalez et al, 2007), reducing oxidative stress, inflammation and DNA damage induced by UV radiation (Verma et al, 2023).

A simulation performed on the Sunscreen Optimizer platform (**Table 5**) demonstrated that the addition of 1% araça extract to formulations containing 7.5% EHMC provided an SPF increase equivalent to the addition of 3.5% Ethylhexyl Dimethyl PABA (EHDP) or 12% Homosalate. In practical terms, this is equivalent to replacing 35g of EHDP or 120g of Homosalate per kg of formulation. This reduced the total organic filter load from 195g/kg to 75g/kg, a 61.5% reduction - without loss of photoprotective efficacy.

The reduction in filter mass directly impacts production costs. By replacing EHDP with araçá extract, the cost of filters decreased from approximately US$1,118 to US$443, representing a savings of approximately 60% (**Table 5**). For homosalate, the reduction was more significant, from approximately US$6,533 to US$443, a savings of over 90%. Thus, *Psidium* and *Eugenia* extracts demonstrate potential not only for increasing the efficacy of sunscreens but also for significantly reducing dependence on synthetic filters, with a direct and significant economic impact.

In addition to technical and economic efficiency, extracts offer sustainability advantages. Because they are biodegradable, derived from renewable plant resources, and obtained from native biodiversity, extracts comply with the *Safe and* Sustainable-by- *Design* (SSbD) principle (51,52)Battistin et al., 2022; Faure et al., 2023), combining performance, economic viability, and reduced environmental impact throughout the product's life cycle.(3,15)

It is worth noting that, in addition to the species studied, other araças also showed photoprotective properties: *Posoqueria latifolia* showed activity against UV-A rays (53); *Pimenta pseudocaryophyllus* revealed a protective effect in animal models (54); and *Psidium guajava* L. showed an increase of more than 100% in the SPF of photoprotective formulations (29). Interestingly, despite belonging to different genera, these araçás share morphological similarities, and popular knowledge often attributes similar properties to them, highlighting the connection between traditional and scientific understanding.

3.3 - Multifunctionality and technological stability of extracts:

Araça fruit extracts reveal a multidimensional phytochemical profile with dermopharmaceutical relevance, whose most consistent effects can be summarized in four axes:

i - Whitening (antimelanogenic). Phenolic compounds and flavonoids (Beltrame et al, 2021), such as quercetin (IC10-15μM), caffeoylmethylquinic and caffeoylquinic acids (IC50 20-30μM), caffeoyl tartaric acid and gallic acid (IC50 5-20μM), present in araças, have the ability to inhibit tyrosinase by chelation of Cu^{++}, (38,55) resulting in reduced melanogenesis and skin uniformization (39). Tests with *Psidium guineense extracts* demonstrated up to 92.9 ± 0.9% tyrosinase inhibition, corroborating the applicability of araças in formulations with a depigmenting effect (56)

ii - Anti-inflammatory. Different species of the genus exhibit significant suppression of pro-inflammatory mediators. Extracts of *P. acutangulum* , por exemplo, reduziram TNFα (−18%), IL-1β (−58%), IL-6 (−32%), e IL-8 (−21%) (25), enquanto *and P. cattelevanum* inhibited COX-2 by 18.3% and 26.5% (38,39). This modulation is attributed to phenolics (gallic and glucogallic acids)(39) and flavonoids such as kaempferol (38), which, in safe topical concentrations, as in the case of araças, act to inhibit inflammatory pathways (19) without compromising cell viability (40).

iii - Healing and regenerating. Catechins and ascorbic acids, common in araças, stimulate collagen synthesis (57), while flavonoids and terpenes (linalool, geraniol) promote cell renewal (39). In vitro, *P. guineense extract* showed potent inhibition of collagenase (-100 ± 0.0%), elastase (-95.3 ± 0.8%), hyaluronidase (-100.0 ± 0.0%), preventing degradation of the extracellular matrix (26). Additionally, kaempferol, in doses compatible with that found in araça fruits (~0.16mg/g kaemferol), has been shown to accelerate the healing of burns (40) and reduce inflammatory mediators, reinforcing its regenerative role (47).

iv - Physicochemical stability. Stability is the main challenge for industrial translation. After four weeks, Mora and Jimtaisong. (2025) observed a slight darkening of color, with maintenance of pH and viscosity, but a reduction in SPF from 34.55 ± 3.27 at 25°C to 30.79 ± 3.08 at 45°C, demonstrating sensitivity to heat stress. Therefore, the adoption of stabilization strategies, such as secondary antioxidants, chelating agents, encapsulation, and pH adjustment during standardization, is recommended(26).

4. Conclusion

The results of this study highlight the potential of ethanolic extracts from araçá fruits as functional additives in photoprotective formulations. The species evaluated— *Psidium cattleyanum* Lucidum, *Psidium guineense* , *Psidium acutangulum* Oblongatum, and *Eugenia stipitata* —demonstrated, to varying degrees, the ability to increase the SPF of formulations containing the synthetic organic filter ethylhexyl methoxynamate (EHMC).

P. guineense extract showed the greatest SPF increase (30%), followed by *P. acutangulum* var. oblongatum and *E. stipitata (28%)* , and *P. cattleyanum* var. lucidum (20%). These results confirm the additive action of araçá fruit extracts. Furthermore, *P. guineense* + EHMC presents performance equivalent to commercial formulations with multiple UV filters, suggesting a synergistic effect with conventional active ingredients. This significantly reduces the need for synthetic filters and, consequently, production costs.

Phytochemical analysis revealed the presence of flavonoids, tannins, terpenes, and phenolic acids in the samples, bioactive compounds recognized for their antioxidant, antimelanogenic, anti-inflammatory, photoprotective, and regenerative properties. These compounds correlate with the UV absorption profile, as species with a greater diversity of compounds (flavonoids, tannins, and phenolic compounds) presented higher AUC and a balanced UVA/UVB balance, although the increase in SPF is not always accompanied by Total Phenolics.

The ripeness stage of the fruits was a determining factor in photoprotective efficacy, with extracts from green fruits exhibiting greater photoprotective potential compared to ripe (yellow) fruits. The presence of terpenes, steroids, and higher moisture content in green fruits were identified as important indicators of greater photoprotective efficacy. These findings suggest that, for more effective formulations of natural photoprotectors, the selection of extracts from green fruits is crucial.

These attributes give the extracts a multifunctionality (antioxidants, antimelanogenic, anti-inflammatory, photoprotective and regenerative) desirable for the development of innovative cosmetics, with a “safe-by-design” approach, especially in the context of safe, effective and environmentally responsible photoprotection.

Given Brazil's rich biodiversity and the growing demand for natural, sustainable, and multi-functional ingredients, araçá fruits are emerging as promising alternatives for sunscreen formulations. Further studies, including in vivo evaluations, stability testing, and dermatological and ecotoxicological safety analyses, are recommended to validate and expand the use of these extracts in the cosmetics industry.

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Figures

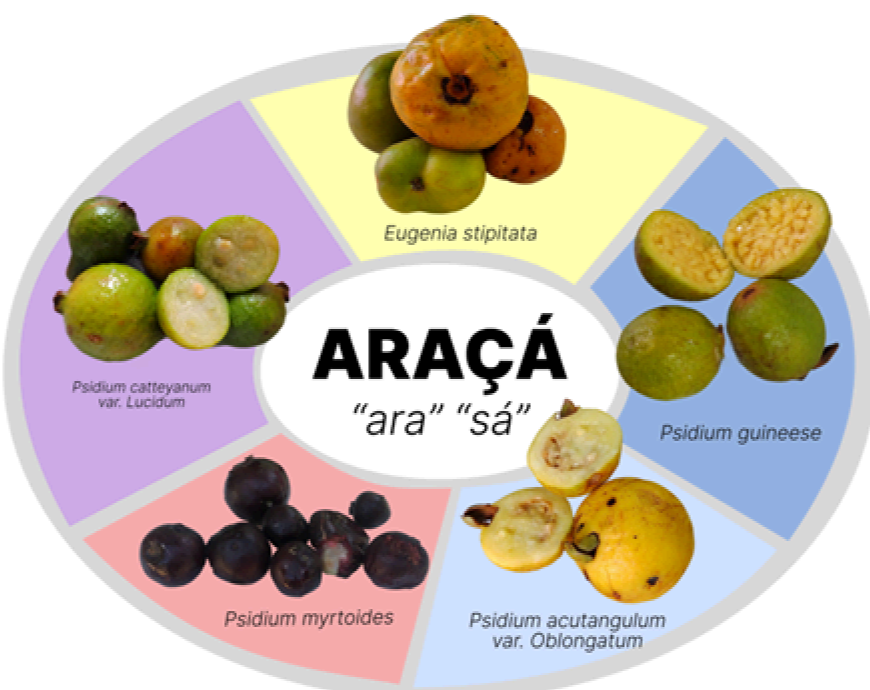


Figure 1

Sample of Araças fruits

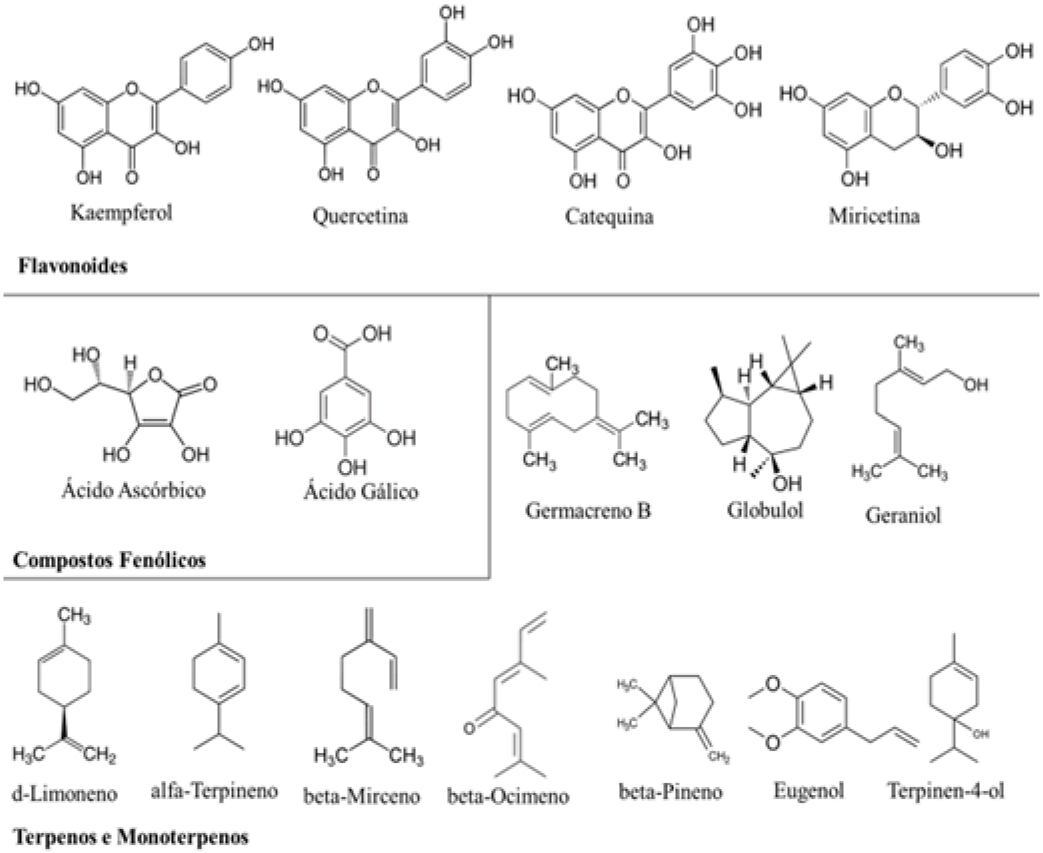
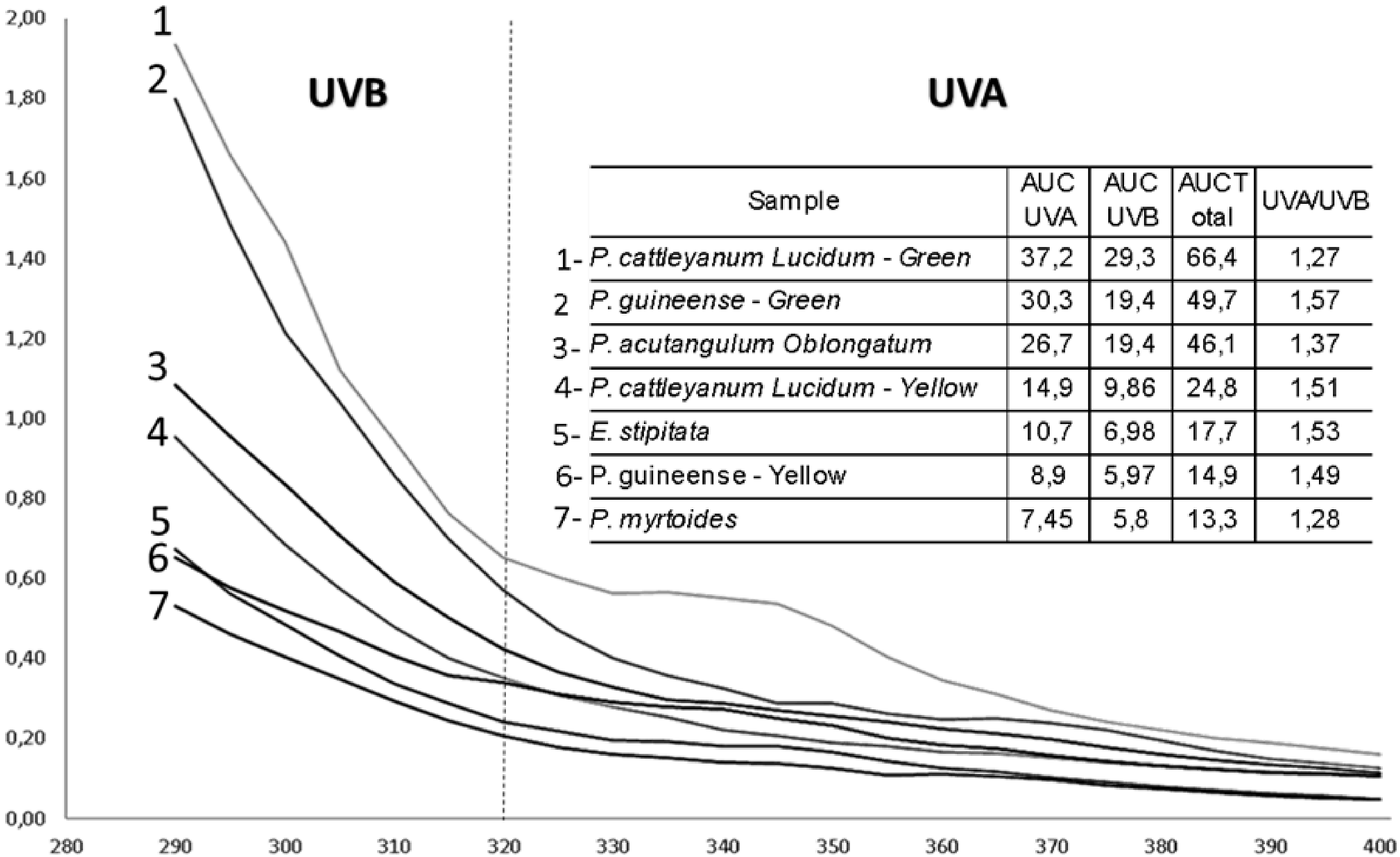


Figure 2

Recurrent bioactive compounds in Araças species

Source: adapted from Andrade et al, 1993; Ramos et al, 2015; Biegelmeyer et al, 2021



	Sample	AUC UVA	AUC UVB	AUCT otal	UVA/UVB
1-	*P. cattleyanum Lucidum - Green*	37,2	29,3	66,4	1,27
2	*P. guineense - Green*	30,3	19,4	49,7	1,57
3-	*P. acutangulum Oblongatum*	26,7	19,4	46,1	1,37
4-	*P. cattleyanum Lucidum - Yellow*	14,9	9,86	24,8	1,51
5-	*E. stipitata*	10,7	6,98	17,7	1,53
6-	P. guineense - Yellow	8,9	5,97	14,9	1,49
7-	*P. myrtoides*	7,45	5,8	13,3	1,28

Figure 3

Absorption of Araça Fruit Extracts in the UVA/UVB bands

Source: Research data; AUC_UVA: Area under the curve for the UVA region (320-400 nm); AUC_UVB: Area under the curve for the UVB region (290-320 nm); AUC_Total: Area under the total curve (sum of the areas for the UVA and UVB regions); UVA/UVB: Ratio between the area under the curve for the UVA region and the UVB region