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Bioactive composition, antioxidant activities, and health benefits of selected tropical horticultural fruit waste

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Abstract. This study sought to evaluate the potential benefits of tropical horticultural fruit waste, its bioactive composition, and possible reasons for its underutilization and to provide comparative knowledge that could be adopted for pharmaceutical, culinary, and therapeutic purposes. Guava seed was found to be richer in β-sitosterol as compared to extracts from the seeds of pawpaw, soursop, passion fruit, pumpkin, mango, grape, tomato, and orange. The sweetness-inducing effect of miraculin from "miracle fruit" and its effect on TAS1R3 and TAS1R2 taste receptors were evaluated. Upon a critical study of existing research data, this study has found the identification of bioactive composition and active ingredient as insufficient in boosting utilization of fruit waste and faulted the relatively low adoption of research findings by consumers and food processing to be due to limited research and awareness on possible methods of processing horticultural waste into readily available, commercializable forms.

Keywords and phrases: mechanism, food enrichment, oxidative stress, therapeutic value, food loss and waste

Introduction

Tropical horticultural fruits typically refer to fruits grown in equatorial or warm-climate areas. They are considered good sources of essential minerals, dietary fibres, and bioactive compounds with varying health benefits. In spite of potential nutritional and therapeutic benefits, parts of fruit, such as peels, rinds, seeds, pomace, and core, are considered waste by most consumers and processing industries despite accounting for a significant portion of the entire fruit weight, with waste generated from fruits such as pineapple and orange accounting for approximately 40% and 55% (w/w) respectively (*Zhang et al.*, 2020). Underutilization and poor food waste management practices have greatly contributed to the growing challenge of environmental pollution, which generates an equivalent of 3.3 billion tons of greenhouse gases annually (*FAO*, 2022).

Global demand for fruit continues to increase due to dietary recommendations. Fruits are characterized by a relatively short shelf life as compared to tuber crops. As such, waste from tropical horticultural fruits poses not only environmental challenges but economic complications as well (*Martínez-Inda et al.*, 2023). In an attempt to address increased cases of undernutrition, particularly in developing communities, food insecurity, and reduced agricultural yield due to climate change, researchers and agro-allied stakeholders alike have sought means of value adding for horticultural waste in order to maximize their nutritional benefits, reduce food waste, and increase food availability. By-products of citrus fruits (seed, pomace, and wastewater) account for 50–60% of the weight of raw fruit after processing or household consumption (*Panwar et al.*, 2021).

This prompted the need for further research into bioactive and proximate compositions as well as suitable methods for reprocessing various tropical horticultural food waste. Tropical fruits such as mango, grapefruit, guava, and orange are rich in vitamin C, a powerful antioxidant known to inhibit free radicals and oxidative stress. Other examples of identified health benefits of horticultural fruit wastes include: anti-inflammatory and anti-proliferation of cancer cells by avocado seed (*Vo et al.*, 2019; *Alkhalaf et al.*, 2019); high dietary fibre in guava seeds, which facilitates improved bowel health and healthy weight loss (*Uchôa-Thomas et al.*, 2014); inhibitory activities of sweet orange *Citrus sinensis* seeds against *E. coli*, *S. aureus*, *Pseudomonas aeruginosa*, and *Salmonella spp.* bacterial (*Oikeh et al.*, 2020).

Value addition for tropical horticultural fruit waste as a primary or secondary raw material in cosmetics, industrial processing, food enrichment, or fortification cannot be achieved without the knowledge of its proximate and bioactive composition. This information helps in determining the most appropriate method of utilization (*Raj & Masih*, 2014). This study seeks to evaluate the potential health benefits of tropical horticultural fruit waste, its bioactive composition, and possible reasons for its underutilization.

2. The chemical composition of selected horticultural fruit waste

The health benefits of fruits cannot be overemphasized, as they serve as important sources of much-needed vitamins, minerals, and bioactive compounds of health-promoting potentials. The quantity of these substances in fruits may vary based on varieties, species, and in some cases the climatic condition of places where they are cultivated. An existing misconception pertaining to health benefits attainable in tropical fruits is continually fuelled by inadequate or misinformation from media platforms, medical practitioners, and nutritionists who often recommend fruits only based on health benefits attainable within the mesocarp, neglecting health-promoting potentials accessible in other parts of the fruit. Examples of this include the predominance of β-sitosterol in the seeds of guava, higher phenolic and flavonoid contents identified in the peels and seed of avocado fruit as compared to its pulp.

Findings from existing literature, as shown in *Table 1*, highlight the concentration of polyphenols and the antioxidant capacities identified in selected tropical horticultural fruit waste. This information is vital for appraising health-promoting potentials and possible means of utilizing the selected fruit waste. High flavonoid and phenolic content often results in increased antioxidant capacity. The presence of different active ingredients identified in different waste parts (*Table 3*) are largely responsible for the observed health benefits of waste parts, as shown in *Table 2*.

2.1. Pineapple

The proximate composition of pineapple peels comprises moisture (82.7%), ash (5.0%), total lipids (1.1%), crude protein (8.8%), and crude fibre (16.3%) on a wet basis (*Morais et al.*, 2017). The pineapple peel is a good source of ascorbic acid and ferulic acid and possesses anti-inflammatory, antioxidant, and antimicrobial properties (*Sah et al.*, 2016; *Lubaina et al.*, 2019). In Nigeria and some parts of Africa, pineapple peel is boiled with roselle calyces to improve its sensory and nutritional attributes. It can also be applied as a condiment in the production of culinary meals (*Wu & Shiau*, 2015). Major phenolic compounds identified in pineapple peels include epicatechin, gallic acid, catechin, and ferulic acid (*Li* et al., 2014). Findings by *Zhang et al.* (2020) indicate fermentation to be an effective means of improving the phenolic and flavonoid content of pineapple peel. The high dietary fibre content of pulverized pineapple peel can also be adopted as an effective means of improving bowel movement and reducing the chances of overfeeding.

2.2. Miracle fruit

Miracle fruit contains anthocyanin, a substance known to reduce or prevent high blood pressure by inhibiting the angiotensin-converting enzyme (ACE) and thereby preventing vasoconstriction (*Raphael et al.*, 2023). The antioxidant nature of anthocyanin also makes miracle fruit an effective means of treating oxidative stress and preventing free-related illness. Miracle fruit contains the uncommon protein "miraculin", which can be used to activate sweet taste receptors in patients following chemotherapy.

Table 1. The phenolic, flavonoid, and antioxidant capacity of selected tropical horticultural fruit waste

Fruit	Parts	Phenolic	Flavonoid	Antioxidant	Reference
Orange (*Citrus sinensis*)	Peel	21.31 mg GAE/g	1.08 mg QE/g	4.79 mg AAE/g	(Suleria *et al.*, 2020)
		35.6 mg GAE/g	83.3 mg CE/g	70.5%	(Sir Elkhatim *et al.*, 2018)
Miracle fruit (*Synsepalum dulcificum*)	Seed	18.55 mg/g	0.88 µg/g	16.94 µmol/g	(Inglett & Chen, 2011)
	Skin	59.54mg/g	5.27 µg/g	27.15 µmol/g	(Inglett & Chen, 2011)
Grapefruit (*Citrus paradisi*)	Peel	27.22 mg GAE/g	0.82 mg QE/g	9.17 mg AAE/g	(Suleria *et al.*, 2020)
		77.30 mg GAE/g	80.8 mg CE/g	76.4%	(Sir Elkhatim *et al.*, 2018)
African star apple (*Ghrysophyllum albidum G.*)	Seed	279.79 mg GAE/100g	116.68 mg CAT/100g	50.67%	(Oluwatoyin *et al.*, 2017)
	Peel	308.30 GAE/100g	160.21 mg CAT/100g	40.14%	(Oluwatoyin *et al.*, 2017)
Pineapple (*Ananas comosus*)	Peel	7.83 mg GAE/g	1.47 mg QE/g	1.30 mg AAE/g	(Suleria *et al.*, 2020)
		11.1 mg GAE/g	3.86 mg QE/g	13.63 µmol TE/g	(Jatav *et al.*, 2022)
Guava (*Psidium guajava*)	Seed	973.80 mg/100g dw	270.3 mg/100g dw	63.74%	(El Anany, 2015)
	Peel	39.65 mg GAE/g dw	19.72 mg RE/g dw	264.3 µmol TE/g dw	(Liu *et al.*, 2018)

Fruit	Parts	Phenolic	Flavonoid	Antioxidant	Reference
Pawpaw (*Carica papaya*)	Seed	9.61 mg GAE/g	0.36 mg QE/g	4.3 mg TrE/g	(Gaye *et al.*, 2019)
	Peel	3.13 mg GAE/g	1.06 mg QE/g	1.33 mg AAE/g	(Suleria *et al.*, 2020)
		15.53 mg GAE/g	0.23 mg QE/g	1.96 mg TrE/g	(Gaye *et al.*, 2019)
Banana (*Musa spp.*)	Peel	6.13 mg GAE/g	1.32 mg QE/g	1.20 mg AAE/g	(Suleria *et al.*, 2020)
		22.95 mg GAE/g	13.68 mg GAE/g	79.03%	(Islam *et al.*, 2023)
Avocado (*Persea americana*)	Peel	123.57 mg GAE L-1	14.09 mg QE L-1	1957.24 µmol TE L-1	(Rotta *et al.*, 2015)
		18.79 mg GAE/g	1.24 mg QE/g	8.67 mg AAE/g	(Suleria *et al.*, 2020)
	Seed	8.72 mg GAE/100g	1.721 mg QE/100g	72.65%	(Siol & Sadowska, 2023)
Mango (*Magnifera indica*)	Peel	27.51 mg GAE/g	1.75 mg QE/g	8.67 mg AAE/g	(Suleria *et al.*, 2020)

Notes: GAE = gallic acid equivalent; QE = quercetin equivalent; AAE = ascorbic acid equivalent; TrE = trelox equivalent; CE =catechin equivalent.

Table 2. Common names of selected tropical horticultural waste and health benefits from waste part(s)

Fruit	Other name(s)	Parts	Health benefits	Reference
Orange	Osan, mchungwa	Peel	Anti-inflammatory, antioxidant, weight loss	(Chen *et al.*, 2011)
Miracle fruit	Miracle berry	Seed	Cardiovascular disease treatment, anti-diabetic, antioxidant	(Huang *et al.*, 2023)
Grapefruit	Pamplemousse	Peel	Antihypertensive, antioxidant, anti-diabetes	(Ademosun *et al.*, 2015; Oboh & Ademosun, 2011)
African star apple	Agbalumo, udara	Seed	Treatment of vaginal and dermatological infections	(Asare *et al.*, 2015)
		Peel	Antimicrobial, antioxidant	(Okoli & Okere, 2010)
Pineapple	Ananas	Peel	Antioxidant, antimicrobial, anti-inflammatory	(Sah *et al.*, 2016)

Fruit	Other name(s)	Parts	Health benefits	Reference
Lemon	Limau	Peel	Anti-inflammatory, anti-tumour, antioxidant, anticancer, antimicrobial	(Wang *et al.*, 2021)
Guava	Guayava, goiaba	Seed	Antimicrobial, anti-inflammatory, anti-cancer	(El Anany, 2015)
		Peel	Hypoglycaemic, antioxidant, weight loss	(Vijaya Anand *et al.*, 2019)
Pawpaw	Papai, ibepe	Seed	Anti-diabetes, anti-hypercholesterolemia, antioxidant, weight loss	(Saba, 2022)
		Peel	Antioxidant, anti-inflammatory	(Dada *et al.*, 2016)
Banana	Ogede, mgomba	Peel	Antioxidant, anti-inflammatory	(Azarudeen & Nithya, 2021)
Avocado	Alligator peer	Seed	Anti-hyperglycaemic, anti-hypertensive, antioxidant	(Bangar *et al.*, 2022)
		Peel	Antitumor, antioxidant, antidiabetic, anti-ageing	(Akan, 2021)
Mango	Mangwaro, mangues	Peel	Antioxidant, anti-cancer	(Ajila *et al.*, 2008)

Table 3. Bioactive compounds identified in selected horticultural wastes

Fruit	Botanical name	Family	Parts	Bioactive ingredients	Reference
Orange	*Citrus sinensis*	*Rutaceae*	Peel	Limonoid, carotenoids, ascorbic acid, protocatechuic acid, hesperidin, Catechin	(Montero-Calderon *et al.*, 2019)
Grapefruit	*Citrus paradise*	*Rutaceae*	Peel	Hesperidin, hesperetin, naringin, flavones, phenols	(Castro-Vazquez *et al.*, 2016)
Pineapple	*Ananas comosus*	*Bromeliaceae*	Peel	Ferulic acid, gallic acid, Catechin, epicatechin, phenols, malic acid, ascorbic acid	(Meena *et al.*, 2022; Rivera *et al.*, 2023)
Lemon	*Citrus limon*	*Rutaceae*	Peel	Terpenes, limonoid, pectin, flavonoid, hesperidin	(Saini *et al.*, 2022)

Fruit	Botanical name	Family	Parts	Bioactive ingredients	Reference
Guava	*Psidium guajava*	*Myrtaceae*	Seed	Oleic acid, linoleic acid	(Uchôa-Thomas *et al.*, 2014)
			Peel	Lycopene, phenols, myricetin, apigenin	(Bertagnolli *et al.*, 2014; Vijaya Anand *et al.*, 2019)
Pawpaw	*Carica papaya*	*Caricaceae*	Seed	Vanillic acid, ferulic acid, glycosides, ferulic acid	(Rodrigues *et al.*, 2019)
			Peel	Papain, chymopapain, pantothenic acid	(Balavijaya-lakshmi & Ramalakshmi, 2017)
Banana	*Musa acuminate*	*Musaceae*	Peel	Catecholamines, phlobatannins, triterpenes	(Hikal *et al.*, 2022)
Avocado	*Persea americana*	*Lauraceae*	Seed	Procyanidins, phenols, ascorbic acid	(Bangar *et al.*, 2022)
			Peel	Rutin, epicatechin, quercetin, chlorogenic acid	(Martínez-Gutiérrez, 2023)
Mango	*Magnifera indica*	*Anacardiaceae*	Peel	Magniferin, benzoic acid, polyphenols, Catechin	(Coelho *et al.*, 2019)

Miraculin induces sweetness by interacting with TAS1R3 and TAS1R2 sweet taste receptors at the gastrointestinal and oral cavity levels, stimulating them under acidic conditions (*Gómez de Cedrón* et al., 2020). This makes miracle fruit an ideal and low-calorie alternative to sugar in sour food or drinks. Miracle fruit seed was found to be typically high in potassium and also a potential treatment for Alzheimer's disease. Other identified bioactive components include phytosterols, lignins, tritepenoids, phenolic acids, and N-cis-caffeoyltyrmine (*Akinmoladun et al.*, 2020; *Huang et al.*, 2023).

2.3. African star apple

African star apple fruit, also known as "agbalumo" or "udara" in Nigeria, is grown predominantly in the tropical parts of Africa. Like the case of miracle fruit, there are limited research studies on the health benefits and alternative methods of utilizing this indigenous fruit. Seeds of African star apples are rich in minerals, such as calcium, magnesium, sodium, and potassium, as compared to African star apple peels (*Abolaji & Henry*, 2015), with a 11.6–23.80% oil yield (*Anang et al.*, 2019; *Omeje et al.*, 2019). Fatty acids extracted from African star apple seed include undecylenic acid and oleic acid, with studies proving the anti-inflammatory properties of undecylenic acid via the inhibition of cyclooxygenase activity (*Van der Steen & Stevens*, 2009), while oleic acid, a mono-unsaturated omega-9 fatty acid, reduces cholesterol and improves cardiovascular health (*Lopez-Huertas*, 2010).

The seed of the African star apple is useful in the treatment of vaginal and dermatological infections (*Asare et al.*, 2015), while its peel possesses antimicrobial and antioxidant properties (*Okoli & Okere*, 2010).

2.4. Orange

Parts of citrus fruit, such as peels, seeds, and rinds, are considered waste and are often discarded despite their therapeutic and nutraceutical values (*Sir Elkhatim et al.*, 2018) and account for half the mass of the entire fruit. Antioxidant and anti-diabetic properties were also observed in the peels of grapefruit (*Ademosun et al.*, 2015; *Oboh & Ademosun*, 2011), while the antifungal activity of orange peel was observed against *Histoplasma capsulatum* and *Aspergillus niger*. Orange peels and seeds showed varying degrees of inhibitory activities against gram-negative and gram-positive bacteria such as *Pseudomonas fluorescens, Pseudomonas aeruginosa, Staphylococcus aureus, Escherichia coli, Proteus spp., Enterococcus faecalis*, and *Salmonella choleraesius* (*Naqvi et al.*, 2021; *Oikeh et al.*, 2020).

Orange peels are also known for their anti-inflammatory, antioxidant, and weight loss properties (*Chen et al.*, 2011; *Chen et al.*, 2017). This was in accordance with findings by *Gosslau et al.* (2018), who attributed reduced inflammation observed in rats to the activation of the $NF_{K}B$ signalling pathway, resulting in increased production of chemokines and induced cell apoptosis. Flavone glycoside (hesperidin), a naturally occurring bioactive compound found in citrus peels, is used in the treatment of central nervous disorders and oxidative stress-related ailments (*Kim et al.*, 2019).

2.5. Banana

Banana peels account for 36.6% of the mass of banana fruit (*Soltani et al.*, 2011), which equates to 52.70 million metric tons of wasted banana peel annually (*Dadrasnia et al.*, 2020). Peels of banana (*Musa spp.*) are rich in minerals and essential fatty acids such as oleic acid, stearic acid, palmitic acid, and linolenic acid (*Mohd Zaini et al.*, 2022), potassium, iron, zinc, magnesium, calcium, carbohydrate, and dietary fibre (*Islam et al.*, 2023; *Kabir et al.*, 2021).

Research conducted by *Sundaram et al.* (2011) indicates higher phenolic and antioxidant activities in unripe banana peel as compared to ripe peel; their findings were in accordance with deductions by *Fatemeh et al.* (2012). Polyphenolic compounds identified in banana peels include rutin, kaempferol-3-rutinoside, triferuloyl-dihexose, quercetin-3-rutinoside, myricetin-deoxyhexose-hexoside, isoquercitrin, p-coumaric acid, and sinapic acid (*Mohd Zaini et al.*, 2022; *Vu* et al., 2018), which can be utilized for their antioxidant, antimicrobial, and anti-inflammatory properties (*Azarudeen & Nithya*, 2021; *Naksing et al.*, 2021).

2.6. Pawpaw

The anti-oxidative nature of pawpaw seed makes it a viable option for protecting non-tumorigenic cells (HepG2) from oxidative stress (*Salla et al.*, 2016). Seeds of pawpaw were also found to contain lycopene, a substance known for its highly reactive nature against free radicals (*Kumar & Devi*, 2022). Utilization of unripe pawpaw is highly encouraged, as studies indicate a higher concentration of potassium, calcium, sodium, magnesium, and phosphorus as compared to waste generated from ripe pawpaw (*Chukwuka et al.*, 2013). *Carica papaya* peels show antioxidant and anti-inflammatory properties (*Dada et al.*, 2016), while the seeds are also known for their anti-diabetes, anti-hypercholesterolemia, antioxidant, and weight loss properties (*Saba*, 2022). Utilization of pawpaw seed and peels is encouraged despite the identified presence of hydrogen cyanide (an anti-nutrient), as research findings indicate a significantly lower concentration of the aforementioned anti-nutrient as compared to its recommended permissible limit consumption (*Egbuonu*, 2017). As such, it can be used in the fortification of foods to improve flavour, colour, or therapeutic benefits (*Omar et al.*, 2020).

2.7. Avocado

Peels and seeds of avocado are increasingly utilized in tea production (*Rotta et al.*, 2015), cosmetics (*Ferreira et al.*, 2022), and baking flour alternatives (*Mahawan et al.*, 2015; *Novelina et al.*, 2022). This, in large part, could be attributed to the increased awareness of its numerous health benefits.

Avocado seed possesses antioxidant, anti-cancer, anti-inflammatory, and anti-proliferative properties (*Alkhalaf et al.*, 2019; *Vo et al.*, 2019), while anti-tumour, antioxidant, antidiabetic, and anti-aging properties have been observed in avocado peels (*Akan*, 2021). The presence of mono-unsaturated fatty acids in its seed and peels also highlights its anti-hypercholesterolemia potential. Identified bioactive compounds in the peels and seeds of avocado fruit include benzoic acid, catechin, pyrogallol, chlorogenic acid, rutin, and protocatechuic acid (*Zaki et al.*, 2020), tocopherols, carotenoids, and procyanidins (*Concepción-Brindis et al.*, 2022; *Rojas-García et al.*, 2022).

2.8. Mango

Mango peels are a good source of phenols, flavonoids, carotenoids, iron, and zinc (*Baddi et al.*, 2015; *Marçal & Pintado*, 2021) and are considered suitable for the production of probiotic foods due to the presence of soluble fibre in mango peels. Studies indicate the anti-asthmatic properties of magniferin (a major bioactive compound identified in mango peel) via the attenuation of Th1/Th2 cell ratio and the activation of T-cell-specific transcription factor GATA-3 (*Imran et al.*, 2017). Mango peels can be dried using various drying techniques, milled, then applied as a food supplement, primary or secondary raw material for baking (*Ajila et al.*, 2008), or in other forms of food processing (*Ajila et al.*, 2010).

2.9. Guava

Findings by *da Silva & Jorge* (2017) indicate a significantly higher concentration of phytosterol (β-sitosterol) in guava seed extract as compared to extracts from seeds of pawpaw, tomato, soursop, orange, grape, passion fruit, mango, and pumpkin. β-sitosterol decreases cholesterol levels in the blood by reducing cholesterol absorption from the diet, thus resulting in improved cardiovascular health (*Saeidnia et al.*, 2014). β-sitosterol identified in guava seed can also be utilized for its neuroprotective, angiogenic, antimicrobial, and antioxidant effects (*Novotny et al.*, 2017). Hypoglycaemic, antioxidant, and weight-loss-inducing effects were observed in guava peels (*Vijaya Anand et al.*, 2019).

Conclusions

Health benefits, bioactive composition, and reaction mechanisms of selected tropically generated fruit waste were evaluated. Anti-tumour, anti-inflammatory, antioxidant, anti-diabetic, anti-microbial, and anti-hypertensive activities identified in different fruit wastes served as significant indicators of their relatively untapped potential. However, during this review, limited advances pertaining to methods of possible utilization of proximate compositions and bioactive components of fruit-generated waste were observed, which could in part be faulted as a key reason for its underutilization. This was evident in the research conducted on African star apples and miracle fruits, for which limited research data was found.

The use of tropical horticultural fruit waste for its wide range of identified nutraceutical and therapeutic values is hereby recommended. The quantity of horticultural fruit waste applicable during food processing or value addition exists at the user's discretion, as no evidence of detrimental effects was identified during this study.

There is need for more research studies, as limited data exists on methods of processing tropical fruit waste into storable and commercializable forms. This, in some parts, would explain the observed hesitation by food-processing industries in incorporating parts of fruit considered waste into their production process or their utilization in the production of entirely new products. There is a need for increased commitment to applied research, as this would offer a replicable pathway for an adoptable method of safely processing horticultural fruit waste.

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