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Research Article

Papaya Seeds (Carica Papaya L.): Nutritional Composition, Phytochemistry, Pharmacological Potential, Food Applications, and Future Perspectives

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Abstract

Papaya (Carica papaya L.) is an economically important tropical fruit belonging to the family Caricaceae and is widely consumed because of its pleasant flavour, nutritional value, and traditional medicinal applications. Although the pulp is the principal edible portion, papaya seeds are commonly discarded during fruit consumption and processing. Increasing evidence indicates that papaya seeds are a valuable source of nutrients and biologically active compounds and therefore represent an underutilised plant resource with considerable nutraceutical and food-industry potential. Papaya seeds contain proteins, lipids, dietary fibre, minerals, phenolic compounds, flavonoids, phytosterols, glucosinolates, and isothiocyanate-related compounds. The seed oil is particularly rich in monounsaturated fatty acids, with oleic acid generally being the predominant fatty acid. Experimental studies have reported antioxidant, antimicrobial, anti-inflammatory, antihelminthic, hepatoprotective, hypolipidemic, and other biological activities associated with papaya seed extracts or seed oil. However, much of the evidence remains based on in vitro or animal studies, and results can vary according to cultivar, maturity, extraction method, solvent, dose, and processing conditions. Some constituents of papaya seeds may also have toxicological or reproductive effects at particular doses, emphasising the need for appropriate safety evaluation before therapeutic or concentrated dietary use. This manuscript reviews the nutritional composition, phytochemical constituents, extraction and processing methods, biological activities, food and industrial applications, safety considerations, and future research prospects of papaya seeds. Greater utilisation of papaya seeds could contribute to waste reduction, development of functional foods and nutraceutical ingredients, and improved economic value of papaya processing by-products.

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1. INTRODUCTION

Papaya (*Carica papaya* L.) is a tropical and subtropical fruit crop belonging to the family Caricaceae. The fruit is widely appreciated for its sweet taste, characteristic aroma, soft texture, and nutritional properties. Papaya contains carbohydrates, dietary fiber, vitamins, minerals, carotenoids, phenolic compounds, and several other bioactive constituents. Traditionally, different parts of the papaya plant, including the fruit, leaves, latex, roots, and seeds, have been used for food and medicinal purposes. Contemporary research has consequently focused on the identification and characterization of bioactive compounds present throughout the plant (Juárez-Rosete et al., 2015; Sharma et al., 2023).

Papaya seeds are small, round to oval structures located in the central cavity of the fruit. Fresh seeds are generally black or dark brown and have a characteristic pungent, peppery, or slightly bitter taste. In many countries, they are removed and discarded during fruit preparation, resulting in the generation of a potentially valuable agro-food waste material. Seeds may constitute a substantial fraction of the fresh fruit mass, and their disposal represents a missed opportunity for recovering nutrients and bioactive substances (Adeneye & Olagunju, 2009).

Recent interest in circular economy approaches and sustainable food production has encouraged researchers to investigate fruit and vegetable processing residues as sources of functional ingredients. Papaya seeds are particularly promising because they contain appreciable quantities of protein, lipids, fiber, minerals, and secondary metabolites. Research has demonstrated that papaya seed oil is rich in oleic acid, while seed extracts contain several phytochemicals associated with antioxidant and antimicrobial properties (Marfo et al., 1986; Nwocha et al., 2019).

The biological activities attributed to papaya seeds have generated interest in their possible applications in nutraceuticals, functional foods, pharmaceutical research, cosmetics, and food preservation. Nevertheless, evidence regarding therapeutic efficacy and safety is still developing. It is therefore important to distinguish experimentally demonstrated biological activity from clinically established therapeutic effects.

This review discusses the nutritional composition, phytochemistry, biological activities, potential applications, safety considerations, and future research directions associated with papaya seeds.

2. Botanical and General Characteristics of Papaya Seeds

Carica papaya is a rapidly growing herbaceous plant that produces a large berry-like fruit. The fruit contains numerous seeds embedded within the central cavity. Papaya seeds have a distinctive black color when mature and are surrounded by a gelatinous aril or mucilaginous layer.

The physical and chemical characteristics of the seeds may vary according to cultivar, geographical origin, environmental conditions, fruit maturity, and processing procedures. These factors can influence the concentration of nutrients and phytochemicals. Consequently, reported values for proximate composition and bioactive compounds are not necessarily identical among studies.

Papaya seeds have traditionally been used as a culinary spice in some regions. Dried seeds can be ground and used as a pepper-like seasoning because of their pungent flavor. Traditional uses have also included preparations intended for digestive and parasitic disorders. Modern research has attempted to investigate some of these traditional claims using laboratory and animal models.

3. Nutritional Composition of Papaya Seeds

Papaya seeds possess a considerable nutritional value despite their relatively small size. Their composition includes protein, lipid, carbohydrate, dietary fiber, minerals, and various minor constituents.

3.1 Protein

Protein is an important component of papaya seeds. Marfo et al. (1986) reported protein contents of approximately 27.8% in undefatted papaya seeds and 44.4% after defatting. The difference illustrates the effect of removing oil on the relative proportion of protein in the remaining seed material.

The protein fraction may contribute to the potential use of papaya seed flour as an ingredient in food formulations. However, additional research is required to establish the amino acid composition, protein digestibility, bioavailability, allergenicity, and effects of different processing methods on nutritional quality.

3.2 Lipids and Seed Oil

Papaya seeds contain a substantial amount of oil. Earlier investigations reported approximately 28.3% lipid in undefatted seeds (Marfo et al., 1986), while subsequent studies have also demonstrated considerable oil yields.

Papaya seed oil is particularly interesting because of its fatty acid profile. Oleic acid is generally the predominant fatty acid, commonly accounting for approximately 70–79% of total fatty acids depending on cultivar and extraction method. Palmitic acid and stearic acid are present in smaller proportions, while linoleic and other fatty acids occur at lower concentrations (Marfo et al., 1986; Nzikou et al., 2010).

One study of papaya seed oil reported approximately 73.5% oleic acid, 15.8% palmitic acid, 5.1% stearic acid, and 4.0% linoleic acid (Puangsri et al., 2005). Another investigation reported that approximately 78.33% of the fatty acids in papaya seed oil were unsaturated, further emphasizing its potential as an edible or industrial oil after appropriate safety and processing assessment (Nzikou et al., 2010).

3.3 Dietary Fiber

Dietary fiber is another important component of papaya seeds. Marfo et al. (1986) reported approximately 22.6% crude fiber in undefatted seeds and approximately 31.8% in defatted seeds. Fiber contributes to the structural characteristics of seed flour

and may support its potential application as a functional ingredient.

3.4 Minerals

Papaya seeds contain several minerals, although concentrations vary among samples. Calcium and phosphorus have been reported in appreciable amounts. Trace elements may also be present, including minerals such as magnesium, potassium, iron, and zinc. The actual nutritional contribution depends on the quantity consumed and the bioavailability of the minerals.

4. Phytochemical Composition

The health-related interest in papaya seeds is not limited to their macronutrient content. They contain numerous secondary metabolites that may contribute to biological activity.

4.1 Phenolic Compounds and Flavonoids

Phenolic compounds are important plant secondary metabolites with antioxidant properties. Papaya seed extracts have demonstrated the presence of phenolic compounds and flavonoids in various phytochemical screening studies. These substances can donate hydrogen atoms or electrons to reactive species and may contribute to the antioxidant capacity of plant extracts.

However, antioxidant activity measured using chemical assays should not automatically be interpreted as evidence of antioxidant effects in humans. Absorption, metabolism, bioavailability, and tissue distribution must be considered when evaluating the physiological significance of these compounds.

4.2 Benzyl Isothiocyanate and Related Compounds

One of the characteristic phytochemicals associated with papaya seeds is benzyl isothiocyanate. Isothiocyanates are sulfur-containing compounds formed from glucosinolate precursors and have attracted substantial research interest because of their antimicrobial and other biological activities.

The presence of glucosinolates in papaya seeds was documented in early compositional research, in which glucosinolates represented the most prominent class among the toxicants examined (Marfo et al., 1986). Hydrolysis of glucosinolate compounds can result in the formation of biologically active products, including isothiocyanates.

4.3 Phytosterols

Papaya seeds also contain phytosterols. These plant sterols may contribute to the nutritional and functional properties of seed-derived ingredients. Phytosterols have been investigated extensively for their role in cholesterol metabolism, although the clinical significance of the amounts present in papaya seed products requires further evaluation.

4.4 Alkaloids, Saponins, Tannins, Terpenoids, and Other Constituents

Phytochemical screening of papaya seed extracts has identified several classes of compounds, including alkaloids, saponins, tannins, terpenoids, glycosides, and phenolic constituents. The profile depends strongly on the extraction solvent and analytical method. Consequently, qualitative detection of a phytochemical class should not be interpreted as proof of a specific pharmacological effect (Sharma et al., 2023).

5. Antioxidant Potential

Oxidative stress occurs when the production of reactive oxygen species exceeds the capacity of endogenous antioxidant defense mechanisms. Plant-derived phenolics and other phytochemicals may contribute to antioxidant activity.

Papaya seed extracts have demonstrated antioxidant activity in several laboratory assays. This activity has been associated with phenolic compounds, flavonoids, and other reducing or radical-scavenging constituents. Different extraction solvents can produce extracts with substantially different antioxidant capacities because solvent polarity affects the compounds recovered.

The antioxidant properties of papaya seeds may have potential applications in functional foods and natural food preservatives. However, further studies should examine antioxidant activity using physiologically relevant models and determine the bioavailability of individual compounds.

6. Antimicrobial Activity

Another extensively investigated property of papaya seeds is antimicrobial activity. Extracts prepared using aqueous, alcoholic, or organic solvents have demonstrated inhibitory effects against selected bacterial and fungal organisms in laboratory experiments.

The antimicrobial activity may be associated with benzyl isothiocyanate and other phytochemicals capable of interacting with microbial membranes, enzymes, or cellular processes. The exact mechanism depends on the organism and the concentration and composition of the extract.

These findings raise the possibility of using papaya seed-derived compounds as natural antimicrobial ingredients in food preservation or pharmaceutical research. Nevertheless, in vitro inhibition zones or minimum inhibitory concentrations cannot be directly translated into clinical efficacy. More extensive studies are needed to establish effective concentrations, toxicity, stability, sensory effects, and interactions with food matrices.

7. Antihelminthic Potential

Traditional medicine has used papaya seeds in preparations intended to address intestinal parasites. Experimental studies have provided some support for antihelminthic activity of papaya seed preparations.

The potential antihelminthic action may be related to isothiocyanates and other phytochemicals. Nevertheless, evidence from controlled human studies remains limited. Therefore, papaya seed preparations should not be considered a substitute for established antiparasitic treatment without appropriate clinical evidence.

8. Anti-Inflammatory and Other Pharmacological Activities

Inflammation is involved in numerous chronic and acute disorders. Experimental studies of *C. papaya* preparations have identified anti-inflammatory activity, although much of the available evidence concerns the plant as a whole rather than isolated papaya seeds.

Papaya seed extracts have also been investigated for possible hepatoprotective, hypolipidemic, metabolic, and anticancer-related effects. A recent review of *C. papaya* summarized evidence for multiple pharmacological activities across different plant parts, while emphasizing that the strength of evidence varies substantially among experimental models (Sharma et al., 2023).

Animal research involving papaya seed oil has suggested possible effects on food consumption, adiposity, metabolic parameters, and inflammatory markers. In one mouse study using a high-fat dietary model, papaya seed oil was investigated for its effects on food consumption, adiposity, and metabolic and inflammatory profiles (de Oliveira et al., 2022). Such findings are promising for hypothesis generation but cannot establish efficacy in humans.

9. Possible Effects on Reproductive Health

Papaya seeds have received particular attention because experimental research has reported reproductive effects. Studies in animals have investigated papaya seed extracts for effects on sperm concentration, sperm motility, and reproductive function. Some reports have suggested that particular extracts may possess antifertility or contraceptive properties.

These observations are scientifically important because they demonstrate that papaya seed constituents can have biologically significant effects at certain doses. However, they also highlight the importance of safety assessment. The presence of reproductive effects in experimental models means that concentrated papaya seed extracts should not be assumed to be harmless simply because the seeds are a food-associated plant material.

Consequently, claims that papaya seeds can safely be consumed in large amounts for therapeutic purposes should be approached cautiously. Human clinical evidence is insufficient to establish an appropriate therapeutic dose or long-term safety profile.

10. Papaya Seed Oil

Papaya seed oil represents one of the most promising products obtainable from the seeds. The oil is characterized by a high proportion of monounsaturated fatty acids, particularly oleic acid.

Physicochemical investigations have demonstrated that papaya seed oil possesses properties suitable for further investigation as a food, cosmetic, or industrial oil. Nzikou et al. (2010) reported substantial unsaturated fatty acid content, while a study of Hong Kong/Sekaki papaya seed oil reported approximately 27% oil in the seeds and approximately 73.5% oleic acid in the oil (Puangsri et al., 2005).

Extraction can be performed using conventional solvent extraction, mechanical pressing, or newer techniques such as ultrasound-assisted extraction. Extraction conditions influence yield, fatty acid composition, oxidative stability, and recovery of minor bioactive compounds. Sustainable extraction methods are therefore an important area for future research.

11. Food and Culinary Applications

Papaya seeds can be processed into several potential food ingredients. Traditionally, dried seeds may be used as a pepper-like seasoning because of their pungent taste. They can also be dried, milled, and incorporated into food formulations in controlled quantities.

Papaya seed flour has potential applications as a source of protein and fiber. However, sensory characteristics, bitterness, pungency, digestibility, and the presence of antinutritional or potentially bioactive compounds must be considered before large-scale incorporation into foods.

Potential applications include bakery products, seasoning blends, functional beverages, snack products, and nutraceutical formulations. Processing techniques such as drying, roasting, fermentation, germination, and defatting may modify the nutritional and phytochemical characteristics of the seeds.

12. Extraction and Processing Technologies

The extraction method is a major determinant of the chemical composition and biological activity of papaya seed extracts. Water and ethanol are attractive solvents for food and nutraceutical applications because of their relatively favorable safety profiles. Methanol, acetone, hexane, and other solvents may provide higher extraction of particular compounds in laboratory research but may not be suitable for direct food applications.

Ultrasound-assisted extraction has been investigated for papaya seed oil and can improve extraction efficiency by enhancing mass transfer. Conventional solvent extraction remains widely used for analytical and industrial research, while mechanical pressing offers a potentially simpler approach for oil recovery.

Future processing systems should aim to maximize recovery of valuable components while minimizing solvent consumption, energy requirements, oxidation, and loss of heat-sensitive phytochemicals.

13. Potential Nutraceutical and Pharmaceutical Applications

The combination of nutrients and bioactive compounds makes papaya seeds promising candidates for nutraceutical development. Possible products include standardized seed extracts, seed flour, antioxidant formulations, dietary fiber ingredients, and seed oil-based preparations.

However, nutraceutical development requires more than demonstration of antioxidant or antimicrobial activity. Standardization of active compounds, determination of bioavailability, pharmacokinetics, dose-response relationships, and interactions with medications, toxicity assessment, and controlled human studies are necessary.

A major challenge is variability. Two papaya seed extracts prepared from different cultivars or using different extraction conditions may have substantially different chemical compositions and biological activities. Standardized extraction and analytical quality-control procedures are therefore essential.

14. Safety and Toxicological Considerations

Although papaya seeds have culinary and traditional uses, their safety should not be assumed at all doses or in all forms. Marfo et al. (1986) identified glucosinolates among the compounds of toxicological interest in papaya seeds. In addition, experimental research has demonstrated reproductive effects associated with some papaya seed preparations.

The distinction between whole-food consumption and concentrated extracts is particularly important. A quantity of seeds consumed as a culinary ingredient may provide a substantially different exposure than a concentrated extract containing high levels of particular phytochemicals.

Pregnant individuals should be particularly cautious with medicinal preparations containing concentrated papaya seed extracts because reproductive effects have been reported in experimental research. More broadly, individuals using concentrated herbal preparations should consider the possibility of interactions with medications and should seek professional advice when appropriate.

Future safety studies should evaluate acute toxicity, subchronic and chronic toxicity, reproductive and developmental toxicity, genotoxicity, allergenicity, and potential interactions with commonly used medicines.

15. Environmental and Economic Significance

Papaya seed utilization can contribute to the valorization of fruit-processing waste. Large quantities of seeds are discarded during juice, puree, jam, and fresh-fruit processing. Recovering oil, protein, fiber, and phytochemicals from this material can potentially reduce waste and generate additional revenue.

This approach is consistent with circular bioeconomy principles in which agricultural residues are converted into higher-value products rather than being discarded. Papaya seed oil could be investigated for food, cosmetic, and industrial applications, while defatted seed cake could potentially be evaluated as a protein- and fiber-rich ingredient.

The economic feasibility of such systems will depend on seed availability, collection costs, drying requirements, extraction efficiency, product stability, regulatory requirements, and consumer acceptance.

16. Research Gaps and Future Perspectives

Despite considerable experimental interest, several important research gaps remain.

First, standardized compositional databases for papaya seeds are needed. Variations associated with cultivar, geographical location, maturity, and processing should be systematically evaluated. Second, more research is required to identify and quantify individual bioactive compounds. Modern analytical techniques such as liquid chromatography–mass spectrometry, gas chromatography–mass spectrometry, and nuclear magnetic resonance spectroscopy can improve characterization.

Third, bioavailability studies are essential. Demonstration of antioxidant or antimicrobial activity in a test tube does not necessarily indicate a similar effect after oral consumption.

Fourth, controlled human clinical trials are needed to establish whether papaya seed preparations produce meaningful health effects. Clinical studies should use standardized preparations and clearly defined doses.

Finally, comprehensive safety studies are necessary, particularly for concentrated extracts. Research should establish safe intake levels and investigate possible reproductive, hepatic, renal, gastrointestinal, and drug-interaction effects.

17. CONCLUSION

Papaya seeds are an underutilized component of *Carica papaya* with considerable nutritional, phytochemical, and industrial potential. They contain appreciable amounts of protein, lipids, dietary fiber, minerals, and diverse secondary metabolites. Papaya seed oil is particularly notable for its high oleic acid content, while seed extracts contain phenolic compounds, flavonoids, glucosinolates, isothiocyanate-related compounds, phytosterols, and other phytochemicals.

Experimental studies suggest that papaya seeds may possess antioxidant, antimicrobial, antihelminthic, anti-inflammatory, metabolic, and other biological activities. Nevertheless, most evidence remains preclinical, and biological activity observed in laboratory or animal studies cannot be equated with proven therapeutic efficacy in humans. In addition, certain seed constituents may have reproductive or other toxicological effects at particular concentrations.

From a food-science and sustainability perspective, papaya seeds represent an attractive opportunity for waste valorization. Development of standardized seed flour, oil, extracts, functional foods, and nutraceutical ingredients could increase the economic value of papaya processing while reducing agricultural waste. Future research should focus on standardized chemical characterization, bioavailability, controlled clinical trials, toxicological evaluation, processing optimization, and regulatory assessment. With appropriate scientific validation and safety controls, papaya seeds may become a useful source of functional ingredients for food, nutraceutical, pharmaceutical, and industrial applications.

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