



Dietary Fiber from Fruit Seeds: Functional Properties, Health Benefits and Food Applications

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ABSTRACT

The fruit processing industry produces substantial wastes from seeds, most of which remains underutilized source of dietary fiber and other bioactive compounds. There is growing interest in sustainable, functional food ingredients, highlighting the potential of fruit seed derived dietary fiber to improve human health and add economic value to the agricultural and food processing industries. This review examines fruit seed derived dietary fiber as a potential ingredient for food formulation and waste valorization. A narrative literature review was undertaken, focusing on peer-reviewed literature published between 2020 and 2026. They were identified using combination of terms related to fruit seeds, dietary fiber, extraction, functional properties, health effects, safety and food applications. Mango, avocado, grape, citrus and apple seeds were emphasized because they are represented by a relatively substantial body of published nutritional, functional, extraction and food application literature. The evidence reviewed suggests that fruit seed dietary fiber demonstrates useful properties such as emulsification, moisture absorption, thickening and antioxidation; making them useful in baking, dairy and meat production. Also, there are associated bioactive compounds such as polyphenols, flavonoids and others that enhance the benefits of fruit based dietary fibers through improved gut health, glycemic control and cardiovascular health. Despite these encouraging results, there are limitations related to compositional variability, extraction procedure standardization, and lack of implementation of emerging technologies. Future research considerations should focus on developing a unified database for dietary fiber composition, seeking ways to incorporate machine learning and artificial intelligence into optimizing food production with dietary fibers and a standardized approach to extraction from fruit seeds. Overall, fruit seed derived dietary fibers have demonstrated capacity to be a sustainable and multi-purpose ingredient but their wider use requires standardized processing, clearer safety assessment and stronger evidence from human studies.

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INTRODUCTION

There has been an expansion in the global fruit industry in recent years; this growth can be attributed to an increased demand for fresh fruits and their processed products, as well as functional foods. Global fruit production was reported to have reached 933 million tons in 2022 and was valued at USD 617.37 billion in 2024 (Rishabh and Krishna, 2025). With this massive processing output, which significantly contributes to food security and economic growth, there are large volumes of by-products or wastes generated, such as peels, pomace, seeds, stones and kernels. Seyyedi-Mansour *et al.* (2024) explains that depending on the processing method and fruit species, these by-products can represent up to 60% of total fruit mass; which is channeled out of the value chain as waste rather than a potential source of functional ingredients. Fruit seeds have been reported to be a rich source of dietary fiber; which includes cellulose and pectin and are said to lower cholesterol and regulate blood sugar (Dragomir *et al.*, 2023). Dietary fibers are broadly classified into soluble and insoluble fibers with different benefits. They are referred to as "Roughages" and are the indigestible part of plant foods. Typically, food sources of carbohydrates break down into sugar in the human body; however, dietary fibers pass through the digestive system mostly intact (Ye *et al.*, 2022).

Residue from fruit processing presents serious concerns to the environment and a problem for the food industry. The continuous accumulation of organic waste contributes to greenhouse gas emissions; while improper disposal leads to air, soil and water pollution, as well as an increase in waste management cost (Nordahl *et al.*, 2023). Consequently, there is a global shift towards a more sustainable production system that reduces the impact of fruit processing waste, giving birth to the concept of "product valorization". Nirmal *et al.* (2023) describes valorization as the process of giving value to fruit by-products; by recovering and utilizing their residues to create high value products thereby minimizing environmental impact. This has changed the perception of fruit seeds to renewable resources with enormous industrial and nutritional potential.

There are numerous bioactive compounds present in fruit seeds and dietary fiber is considered one of the most important due to its established and widely reported physiological benefits and food applications (Guan *et al.*, 2021). Furthermore, research indicates that the physiological potency of dietary fibers depends majorly on their solubility (as an important physiochemical characteristic). Venter *et al.* (2022) describes soluble fibers when consumed, as viscous and gel like, which helps to regulate blood glucose levels,

reduce cholesterol concentration and promote beneficial gut micro biota. Also, fiber intake has been reported to reduce risk of obesity, type 2 diabetes, cardiovascular diseases and several other gastrointestinal disorders (Perera *et al.*, 2022). With clinical evidence and wide acceptance of the benefits of dietary fiber, there is still insufficient consumption globally (Tao *et al.*, 2023) and has resulted in growing need for sustainable and affordable sources of fibers. In recent years, there has been increased interest in fruit seeds as a viable source of dietary fiber. Kumoro *et al.* (2025) suggests that fruit seeds contain cellulose, hemicellulose, lignin, pectin, and other non-starch polysaccharides. Furthermore, fruit seeds from date palms (*Phoenix dactylifera* L), apple (*Malus domestica*), mango (*Mangifera indica*), watermelon (*Citrullus lanatus*), citrus (*Citrus spp.*) and others have shown to contain bioactive compounds (such as phenolic compounds, flavonoids, lipids, vitamins and minerals), with favorable physiochemical properties (Allaqaband *et al.*, 2022); which have found applications in food preservation, functional foods and disease prevention (Shafi *et al.*, 2025). Despite growing interest in fruit seed valorization, important gaps remain. Existing studies differ in fruit species, cultivar, maturity, sample preparation, analytical methods and extraction conditions making direct comparison difficult. In addition, health evidence is often derived from general dietary fiber studies rather than from interventions using fibers derived from fruit seeds. Therefore, this review brings together evidence on the composition, extraction, functional properties, health related evidence, safety considerations and food applications of dietary fiber from selected fruit seeds while highlighting the methodological gaps that currently limit comparison and wider food use.

MATERIALS AND METHODS

This article was structured as a narrative review rather than a systematic review. Literature published primarily from 2020 to 2026 was considered, with earlier publications retained where they provided foundational information or were directly relevant to the composition, safety, analytical characterization or application of fruit seeds. Extensive research was conducted using Google scholar, Science Direct, PubMed central and Web of Science search platforms. Searches were based on combinations of the terms “fruit seed”, “food application”, “safety”, “antinutritional factors” and the names of the major fruit seeds discussed in the review. Peer-reviewed original research articles and review articles were prioritized. Studies were considered when they reported information relevant to the fiber composition, extraction, physicochemical or functional properties, biological effects, safety or food applications. Publications not directly related to fruit seeds or dietary fiber, duplicate records, and sources lacking sufficient information for the claims discussed were excluded. The literature was organized thematically and synthesized quantitatively. No formal meta-analysis was conducted, and the review does not claim to follow a systematic review protocol. Because the review is narrative, the selected fruit seeds were not intended to represent an exhaustive ranking of all fruit seeds. Mango, avocado, grape, orange and apple were emphasized because they have a comparatively developed body of published literature covering composition, functional characteristics, processing and food applications.

Classification of Dietary Fiber

Dietary fiber according to the Codex Alimentarius Commission (CAC) can be classified into three categories: (a) naturally occurring in consumed food (b) obtained from food

raw material by physical, enzymatic or chemical means and (c) synthetic carbohydrate polymers (Nancy and Joanne, 2021). These polymers are said to have ten or more monomeric units that are usually not absorbed by the small intestine (of human beings). The definition by CAC views dietary fiber as a group of physiologically active substances with capabilities that improve human health. Dragomir *et al.* (2023) suggests dietary fibers chemically consist of cellulose, hemicellulose, pectins, β -glucans, inulin, polydextrose, mucilages and others.

Soluble dietary fibers dissolve in water and comprises of carbohydrate polymers (Nancy and Joanne, 2021). They are also easily fermented by gut microbiota, leading to the production of fatty acids, propionate and butyrate (Shafi *et al.*, 2025). Gut microbiota are healthy bacteria populations that assist with lowering inflammation and healing the walls of the human intestines (Muhammed *et al.*, 2022). Insoluble dietary fiber exhibits limited solubility in water and minimal fermentation by gut microbiota (Timm *et al.*, 2023). Dragomir *et al.* (2023) noted that, unlike soluble fibers, insoluble fibers retain their structural integrity all through the intestinal tract and functions as an accelerator for intestinal transit, preventing constipation and colon cancer.

Similarly, dietary fibers can be classified as resistant starch, non-starch polysaccharides and resistant oligosaccharides (Myhrstad *et al.*, 2020). According to Kumoro *et al.* (2025), resistant starch is chemically classified as starch but resembles dietary fibers physiological behavior and is fermented in the large intestine. Non-starch polysaccharides make up the largest proportion of dietary fiber in plant materials and show considerable chemical diversity in composition, solubility and fermentability (Myhrstad *et al.*, 2020). Also, oligosaccharides are found in a limited number of plant foods such as lentils, onions and garlic; which are composed of three to eight basic sugars (Gush *et al.*, 2021).

Fruit Seeds as Sources of Dietary Fiber

Shafi *et al.* (2025) suggests that the fiber composition of fruit seeds may vary significantly among species; and may be influenced by fruit maturity, cultivation practices, genetic composition and processing techniques. The following are some fruit seeds with significantly published literature and investigations into their fiber contents. A summary of the findings is presented in Table 1.

Mango (*Mangifera indica*)

Mango is a sweet stone fruit with juicy yellow-orange flesh with an edible tough outer skin. They are considered one of the most widely cultivated tropical and subtropical fruits which generate large quantities of seeds as waste from juice, pulp and concentrate production. Mango has a significant number of varieties with economic importance in the food industries due to its richness in dietary fiber, vitamins, minerals, and antioxidant compounds (Galib *et al.*, 2022). They further reported that mango fiber concentrates demonstrated significant physiochemical properties such as a high level of DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging activity, polyphenol and ascorbic acid contents. Mango kernels are reported to have a balanced amount of soluble and insoluble fiber (Timm *et al.*, 2023); and can exhibit good amount of crude protein (6.51%), crude fat (8.79%), total carbohydrate (82.88%), starch (34.07 g/100 g) and dietary fiber (9.81 g/100 g) (Mwaurah *et al.*, 2020).

Avocado (*Persea Americana*)

Avocado, otherwise known as alligator pear is a single seeded berry native to the Americas. Its seed is large, oval shaped and forms between 10-25% of fruit weight, with moisture and

oil content making up to 30% (Afzal 2022). Avocado seeds are frequently considered as waste, but have been reported to contain considerable amount of dietary fiber (Ramya et al., 2025).. Futhermore, extracts from its seed may contain

antioxidants (i.e., high polyphenols with radical scavenging capacity), antimicrobial (which inhibits bacteria like *E. coli*, fungi like *Candida albicans*), antidiabetic and anti-inflammatory attributes (Ramya et al., 2025).

Table 1: Characteristics of Major Fruit Seeds

Fruit seed	Dietary fiber content/ fiber content	Predominant fiber type	Key bioactive compounds	Availability/processing context	References
Mango	0.24-4.69% crude fiber (dry basis)	Predominantly insoluble; soluble fractions also reported	Mangiferin, gallic acid, ellagic acid, catechins, tannins	Large processing stream; seed and kernel residues are substantial	Mwaurah et al., 2020
Avocado	69.2 g/100 g dry matter	Predominantly insoluble polysaccharides	Catechins, chlorogenic acid, procyanidins, phytosterols	Increasingly investigated as a processing by-product	Setyawan et al., 2021
Grape	40.2-43.7 g/100 g total fiber	Mainly insoluble	Proanthocyanidins, gallic acid, catechins, resveratrol	Large by-product stream from wine/juice processing	Prata et al., 2025; Elkatry et al., 2022; Haia et al., 2022
Orange	5.49-6.06% crude fiber (dry basis), depending on variety	Predominantly insoluble; soluble pectin also reported	Hesperidin, naringin, limonoids, carotenoids	Generated during juice processing	Joseph et al., 2021; Adubofuor et al., 2021
Apple	3.92-4.32% fiber	Largely insoluble	Phloridzin, flaonoids, tocopherols, chlorogenic acid	Generated during apple processing; safety assessment important	Manoj et al., 2022; Kumar et al., 2022; Kumar et al., 2024

Avocado seeds are composed majorly of insoluble polysaccharides such as hemicellulose, with smaller amounts of soluble fiber; which contain bioactive compounds such as carotenoids, flavonoids, vitamin C, and phenolics (Setyawan et al., 2021).

Grape (*Vitis Vinifera*)

There is increased interest in grape seeds as there are enormous amounts generated by the wine and juice industries. They are from a small, juicy fruit with green, red, purple, or black skin. Elkatry et al. (2022) reported that grape seeds may contain high polyphenol contents and significant amounts of insoluble dietary fibers. These polyphenols are majorly found in seeds (60-70%) compared to grapefruits (10%) and peels (28-35%); and are linked to improved cardiovascular effects, antioxidant properties, anti-inflammatory effects, and anticancer activity (Elkatry et al., 2022). Additionally, Ivanov et al. (2025) opines that grape seed extracts are rich source of polysaccharides, proteins and vitamins which are interesting bioactive substances, with several studies showing that they inhibit salivary α -amylase which aids diabetes control.

Orange (*Citrus Sinensis*)

Oranges are widely used in juice extractions and processing which produces significant amounts of seeds, particularly in regions such as Brazil, China, the United States associated with citrus production. Although orange peels have received more attention and investigated for their potential health benefits, orange seeds have been reported to have appreciable dietary fiber with vital phytochemicals (Adubofuor et al., 2021). Orange seeds are reported to contain predominantly insoluble fibers (i.e. cellulose and hemicellulose) as well as small amounts of soluble fibers (i.e. soluble pectin). Adubofuor et al. (2021) further reported that orange seeds contain high fiber, energy, vitamin C, potassium, calcium and alkaloids; a conclusion reached after studying the nutrient compositions of two orange seed varieties (Late Valencia and Red Blood).

Apple (*Malus Domestica*)

Same as seeds from previously described fruits, apple seeds are commonly discarded as waste, however they also possess abundant nutritional benefits (Suhag and Gasparini, 2024). Recent investigations suggest that apple seeds are rich sources of fiber (3.9-4.3%) , amino acids, fatty acids (linoleic and oleic acids), and polyphenolic compounds such as phlorizin which have been reported to be effective in treating obesity and type 2 diabetes (Kumar et al., 2022). Others include hyperin, chlorogenic acid, and epicatechin.

Dietary Fiber Extraction Techniques

To optimize the quality and quantity of fiber extracted from fruit seeds, the correct technique must be employed to preserve the physicochemical properties, molecular structures and solubility of extracts (Feng et al., 2023). Also, the choice of extraction techniques depends on the intended application, processing cost, environmental considerations and botanical origin of seeds (Liu et al., 2025). Below are some convectional extraction techniques that have gained considerable attention for their sustainability and limited environmental impacts.

Enzymatic Extraction (EE)

This method of extraction uses biological catalysts (such as microbial protease) to penetrate fruit seeds to release dietary fibers. This method avoids the use of harsh solvents which preserve the purity of the extracts (Viscusi et al., 2024). Nguyen et al. (2025) describes the impact of various advanced extraction methods (including enzymatic) on the polychemical properties of soluble dietary fibers from *Citrus sinensis*; suggesting different methods impacted distinct characteristics of soluble dietary fibers. The report further suggests that EE had the most fiber yield with high oil holding capacity.

Ultrasound-Assisted Extraction (UAE)

UAE is an advanced and sustainable technique that utilizes mechanical vibrations at frequencies higher than 20 kHz to

enhance seed penetration and cavity penetration (Buljrta *et al.*, 2023). This technique is used to enhance penetration of seeds to create cavities; after which solvents are used to release fiber and other bioactive compounds, reducing extraction time and solvent consumption (Roobab *et al.*, 2025). Furthermore, optimization of ultrasound frequency and processing temperature will prevent excessive degradation of fiber polymers whilst reducing energy and time required (Hina *et al.*, 2023). Siddiqui *et al.* (2023) also suggests that this extraction method can improve functional properties of dietary fibers like water or oil holding capacity and gel-forming capacity.

Microwave Extraction (ME)

This approach combines the application of microwaves and conventional extraction of fiber from seeds using solvents to increase yield, reduce processing time and reduced applied solvents (Buljrta *et al.*, 2023). This method uses electromagnetic radiation to heat up water molecules in seeds thereby creating internal pressure that facilitates the release of high yield dietary fiber; making the technology suitable for industrial scale extraction of fibers, antioxidants, and polyphenol extracts (Araújo *et al.*, 2020). Some conventional techniques such as drying, milling etc., are inexpensive and require basic machines or materials to execute; however, they can be time consuming and not sustainable.

Dietary Fiber Properties and Characterization

The fiber properties of seeds can be looked at from two categories: physicochemical characterization and functional properties. Some property characterizations may include viscosity, water holding capacity, water solubility, swelling, oil binding, surface area characteristics (Dragomir, *et al.*, 2023). Similarly, dietary fibers can be explored through some functional properties such as emulsification, gel-formation, antioxidant capacity, foam stabilization and texturization (Dragomir *et al.*, 2023). These properties underscore the suitability of dietary fibers for food formulation and related industrial applications.

Water Solubility

This refers to the ability of dietary fibers to dissolve in water; which may depend on several internal and external factors like structure, temperature or pH value.

Viscosity

This describes the resistance of soluble fibers to the flow of solutions. It is a physical property that is closely related to the chemical structure of dietary fibers and influenced by temperature, pH, and processing conditions (Chen *et al.*, 2022).

Water Holding Capacity

This describes the amount of water dietary fiber can retain under certain conditions. It is otherwise referred to as hydration capacity, water binding capacity, or water absorption capacity of dietary fibers, which may influence texture, color and sensory attributes when used in food applications (Shen *et al.*, 2022).

Emulsification

Emulsifiers are substances that help mix or stabilize mixtures that are otherwise unmixable; just as in the case of oil and water. Tang and Huang (2022) opines that whilst dietary fiber isn't classified as an emulsifier, it has been reported to contain polysaccharides and associated proteins known to improve emulsion stability by increasing viscosity.

Gel-Formation: Gels are viscoelastic materials or ingredients that possess physical characteristics resembling liquids and solids depending on experimental conditions. Soluble dietary fibers are preferred over insoluble ones as ingredients in food applications and beverages; due to better gel formulation and emulsification (Nevara *et al.*, 2021). Dragomir *et al.* (2023) suggests that this is because dietary fibers can be used as thickeners without affecting taste, texture and gel formation.

Antioxidation Capacity

Dietary fibers from fruit seeds are said to contain substantial quantities of natural antioxidant phytochemicals such as flavonoids, tannins and carotenoids (Barakat *et al.*, 2020). These dietary fibers can prevent food quality deterioration by contributing to scavenging reactive oxygen species and reducing lipid oxidation. (Oluwole *et al.*, 2022).

Health Benefits of Dietary Fibers from Fruit Seeds

Gut Health

Pamu *et al.* (2026) describe gut health as the maintenance of gastrointestinal structure and its normal function; which includes digestion, balance intestinal microbiota, immune competence and protection against unhealthy or pathogenic microorganisms. They further suggest that disruption to gut microbial balance has been linked to obesity, diabetes, cardiovascular disorders, and inflammatory bowel diseases. Shafi *et al.* (2025) explained that dietary fiber from fruit seeds is processed by gut bacteria to produce short-chain fatty acids that strengthens gut lining, which consequently supports the immune system. Another key benefit of dietary fiber to gut health is improved bowel function. The presence of insoluble fibers like cellulose or lignin absorbs water and resists microbial degradation which increases stool volume, softness and shortens intestinal transit time (Lai *et al.*, 2023).

Cardiovascular Health

The relationship between cardiovascular health and diet has evolved leading to lifestyle modifications like diet changes as a primary approach to managing cardiometabolic risk factors (Diab *et al.*, 2022). Ioniță-Mîndrican *et al.* (2022) reported that several epidemiological studies, clinical trials, and testing have associated higher dietary fiber intake from fruit seeds with reduced hypertensive and cardiovascular mortalities. Also, dietary fibers from fruit seeds have cholesterol-lowering effects; primarily attributed to soluble fractions (such as pectins or hemicellulose) which form viscous gels within the intestine that binds cholesterol, and prevents its reabsorbing (Ioniță-Mîndrican *et al.*, 2022).

Glycemic Control

This refers to the management and control of blood sugar levels by monitoring glycosylated hemoglobin (HbA1c), diet balancing and taking medications (Müller-Wieland *et al.*, 2022). Rakhis *et al.* (2022) opines that higher dietary fiber intake can be associated with enhanced glycemic control, improved insulin sensitivity, and reduced risk of type 2 diabetes mellitus. Similarly, Hebbar *et al.* (2026) conducted a study analyzing thirteen randomized controlled trials, with six evaluated specifically for insulin resistance, using high-fiber dietary products. The outcome was a positive trend indicating reduced homeostatic model assessment for insulin resistance, enhancing insulin sensitivity and decreased insulin levels.

Antioxidant Activity

Oxidative stress, which is the imbalance between free radicals and antioxidants in the human body, is a major contributor to numerous chronic diseases such as cardiovascular disease,

type 2 diabetes mellitus, cancer and even obesity (Sies, 2020). Dietary fiber from fruit seeds is said to be natural sources of antioxidants due to its close association with important phytochemicals such as polyphenols, flavonoids, phenolic acids and tannins (Perera *et al.*, 2022). These antioxidants are useful in preventing oxidative stress-related diseases and are applied in food technology as healthier natural preservatives (Bensid *et al.*, 2022). Mittakos *et al.* (2025) suggests that in food applications, fruit seed dietary fibers are employed to delay lipid oxidation, reduce color deterioration, and extend product shelf.

Safety and Regulatory Considerations

The nutritional and technological potential of fruit seed ingredients should be considered together with safety and regulatory requirements. Fruit seeds can contain antinutritional factors, cyanogenic glycosides, pesticide residues, mycotoxins, heavy metals and other contaminants depending on species, cultivation conditions, handling and processing (Kumar *et al.*, 2024; Tadesse Tsegay *et al.*, 2025). Apple and some other Rosaceae seeds contain cyanogenic glycosides such as amygdalin, which can release hydrogen cyanide when seed tissues are disrupted, therefore, processing and intended concentration levels require careful evaluation (Kumar *et al.*, 2024). Orange seeds have also been reported to contain antinutritional factors including oxalate, phytate, saponins, nitrate and cyanide (Abdubofuor *et al.*, 2021). In addition, allergenicity and possible microbial or chemical contamination should therefore include identification and quantification of relevant toxicants and antinutrients, assessment of processing effects on their levels, contaminant monitoring and determination of appropriate levels in finished foods. Regulatory acceptance should be established for the specific seed material rather than assumed from its nutritional composition alone.

RESULTS AND DISCUSSION

Applications of Fruit Seed Dietary Fibers in Food

The use of natural sources of fiber has increased significantly because of the demand for healthier and sustainable food products. Below are functional food applications of dietary fibers from fruit seeds.

Baking and Bakery Products

The use of fruit seed fibers in baking products is one of the most common applications in food production. They have been successfully used in the baking of cookies, bread, cakes and other baked products to improve taste, nutritional value and prolong shelf life. Dragomir *et al.* (2023) suggests that dietary fibers have a much higher capacity to absorb and retain water than gluten, helping dough hydration and prolonged freshness. However, this could result in reduced loaf volume, increased weight loss, crumb structure and hardness of bread (Xu *et al.*, 2021).

Dairy Products

In dairy products like ice cream and yoghurt, dietary fibers are used as thickeners and stabilizers to avoid separation and improve texture. They also increase the creaminess in ice cream and prevent the formation of crystals when freezing (Núñez-Gómez *et al.*, 2023). Cheese production is said to have a problem of syneresis; an addition of dietary fiber can prevent this by managing water phase and improving texture (Dragomir *et al.*, 2023).

Meat Production

The meat industry is not left out in the quest for sustainable and healthy approach to preservation and production; giving way for increased research and development on the integration of dietary fibers. Manoliu *et al.* (2024) conducted a review of fruit fiber on meat products and suggests that addition of dietary fiber has effects on the physical characteristics, sensory attributes, and can prolong shelf life of meat products. Furthermore, an increased cooking yield, enhanced moisture retention and better texture may be observed depending on application.

Current Limitations and Future Research Considerations

The expansion in research towards the application of dietary fiber from fruit seeds has been productive with positive consumer and production feedback. However, the current applications still have certain limitations and knowledge gaps, where further research efforts should be channeled.

Variation in Fiber composition from different fruit species: fruit seeds may contain dietary fiber and other bioactive compounds; however, this varies in amount, composition and quality with varying fruit species, stage of maturity, cultivars and even extraction method. Similarly, for fruit seeds of the same species, fiber concentration and makeup may vary due to varying conditions like soil composition, irrigation practices and climate (Stojanovska *et al.*, 2023). This makes it difficult to make comparisons and establish standards for synthesizing, food application and reporting.

To close the knowledge gap from these limitations; future investigations must focus on documenting (after empirical studies) a comprehensive database for composition of major fruit seed species and implementing a standard for classifying fruit seed dietary fibers.

No standardized extraction and characterization methods: there are no universally accepted approaches to extracting and characterizing fibers, making it difficult to compare studies. Researchers have utilized methods such as drying, milling, solvent system and other advanced techniques like enzymatic treatment, ultrasound-assisted and microwave extraction. All of which have significant differences in extraction yield, fiber composition, and antioxidant composition.

Future research focus should be on developing an international standard procedure for dietary fiber extraction and unifying physiochemical characterization methods.

Process optimization and emerging technologies: Artificial Intelligence (AI), machine learning, and related data-computational models are some emerging technologies with capabilities to optimize food processing procedures. Despite their increased applications in food productions, there are few studies where these are applied to extraction of dietary fibers from fruit seeds.

Future research focus should be on optimizing extraction and application of dietary fibers in food, using computational models and advance simulations. These models could be designed to predict quality, shelf-life of products and quality control.

These are some limitations affecting the effectiveness of dietary fibers from fruit seeds and addressing them will require multidisciplinary collaboration from food scientists, microbiologists, data scientists, computer modelling experts, and other industry experts.

CONCLUSION

Fruit seeds have emerged as an enterprising and sustainable source of dietary fibers with reasonable potential for various applications in the food industry. The recent shift is associated with the increasing demands by consumers for

healthier diets, concerns regarding food waste and environmental sustainability. This review demonstrates that fruit seeds from mango, avocado, grape, orange, apple and others are sources of important dietary fibers and other bioactive compounds.

This review also acknowledges and highlights several limitations such as lack of standardized extraction and characterization methods, variability of composition of different species and their consequent impact on analysis as well as limited use of emerging technologies such as Artificial Intelligence and computational analysis to better understand and incorporate fruit seed based dietary fibers in food production. In addressing these limitations; there is need for coordinated multidisciplinary research into obtaining a unified database for classifying fiber composition for fruit seeds, a standardized and globally recognized method of extraction as well as ways to optimize the use of emerging technologies to better utilize fruit seeds in food production. With continuous research and development, supported standardized procedures and more clinical trials; we can unlock the full potentials of dietary fibers and promote the transition from food waste to high valued functional and nutritional ingredients.

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