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REVIEW ARTICLE

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# Non-edible fruit seeds: nutritional profile, clinical aspects, and enrichment in functional foods and feeds

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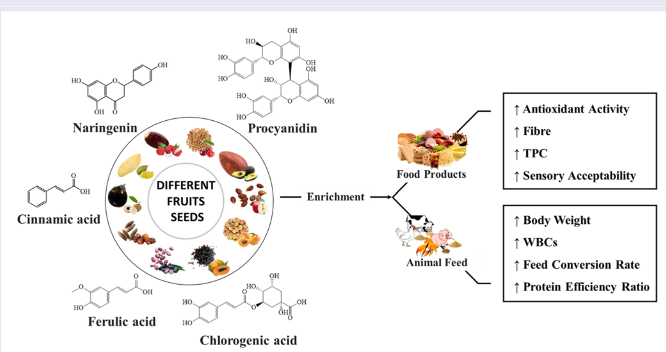
**ABSTRACT**
Nowadays, fruits are gaining high demand due to their promising advantages on human health. Astonishingly, their by-products, that is, seeds and peels, account for 10–35% of fruit weight and are usually thrown as waste after consumption or processing. But it is neglected that fruit seeds also have functional properties and nutritional value, and thus could be utilized for dietary and therapeutic purposes, ultimately reducing the waste burden on the environment. Owing to these benefits, researchers have started to assess the nutritional value of different fruits seeds, in addition to the chemical composition in various bioactive constituents, like carotenoids (lycopene), flavonoids, proteins (bioactive peptides), vitamins, etc., that have substantial health benefits and can be used in formulating different types of food products with noteworthy functional and nutraceutical potential. The current review aims to comprehend the known information of nutritional and phytochemical profiling of non-edible fruits seeds, viz. apple, apricot, avocado, cherry, date, jamun, litchi, longan, mango, and papaya. Additionally, clinical studies conducted on these selected non-edible fruit seed extracts, their safety issues and their enrichment in food products as well as animal feed has also been discussed. This review aims to highlight the potential applications of the non-edible fruit seeds in developing new food products and also provide a viable alternative to reduce the waste disposal issue faced by agro-based industries.

**KEYWORDS**
Bioactive compounds; composition; food enrichment; fruit seeds; value-added products

**GRAPHICAL ABSTRACT**

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## Introduction

Due to the frightening increase in rates of population growth, feeding the world is a huge task (Singh et al. 2021). By 2050, the world population is predicted to reach 9.6 billion (Mishra, Joshi, and Zhao 2018). Around 46 million people were impacted by hunger in 2020 and 150 million since the COVID-19 pandemic, thus bringing the total number of hungry people on the planet to 828 million in 2021 (WHO 2022). The world is getting further away from its vision of eradicating malnutrition, food insecurity, and hunger in all of its forms by 2030, according to the United Nations report (WHO 2022).

By endangering the sustainability of the food system and placing more burdens on the already vulnerable global food production system, the escalating amount of food waste is emerging as one of the big concerns with global food production (Ali et al. 2022). Despite the fact that 28% of farmland is exploited, about 1.3 billion tonnes of food are squandered worldwide (Jensen et al. 2021). It results in nearly one-third of the annual loss in global food production, or the worldwide yield of 1.4 billion hectares of agriculture (Jensen et al. 2021). According to these predictions, urban waste will amount to 138 million tonnes by 2025, causing a serious loss of other resources, including useful land, water, labor and energy (Garcia, Lovett, and You 2019; Liu et al. 2021). Fruit production as an agribusiness is likely to contribute to a significant amount of waste generation, with around 45% of the production waste in the supply and usage chains, resulting in a considerable amount of waste (Guarnieri et al. 2021; Jeswani, Figueroa-Torres, and Azapagic 2021). Losses from transportation and handling range between 25% and 30% (Tollington et al. 2019). Furthermore, about 5.5 megatons (Mt) of waste are produced during the production of fruit juice, up to 5–9 Mt of organic waste from grapes and other fruits by the manufacturers each year and out of which 20–30% waste is processed (Iqbal, Schulz, and Rizvi 2021; Vigneshwar et al. 2022). Nearly 6 Mt of food waste is generated annually by other industrial food sectors, such as canning and freezing, which accounts for 20-30% of stalks, leaves and stems (Eixenberger et al. 2022; Vigneshwar et al. 2022). Lin and Zheng (2021) reported that annual production of mango (*Mangifera indica*) seed can reach $6.3 \times 10^4$ tons only in Taiwan. In apple 20–30% total waste weight come from solid part such as seed (Qin et al. 2021).

Beyond livestock feed, extensive research has been done in recent years to find new value-added products from fruit wastes, particularly from seeds (Wadhwa, Bakshi, and Makkar 2015; Alves et al. 2021). Utilizing innovative industrial techniques, such as optical sorting, which precisely separates the intact, entire seeds from pits, can maximize the value of agricultural by-products such as fruit seeds by reusing the waste to recover the seeds for immediate use (Alves, Simoes, and Domingues 2021). Additionally, these wastes can be exploited to extract valuable phytochemicals or oils for human nourishment from fruit seeds (Fidelis et al. 2019). However, Granato et al. (2020) stated a scientific definition of functional foods as either natural or industrially processed foods that when consumed regularly as part of a diverse diet at effective levels are believed to offer health benefits beyond their fundamental nutritional value. Furthermore, due to healthy eating practices and the desire for the functional foods from end users, the usage of plant and fruit seeds for human consumption has considerably increased in Western countries (Alves, Simoes, and Domingues 2021). Seeds store a lot of nutrients as energy reserves, which are available in their lipid content (Matthäus and Özcan 2015; Raihana et al. 2015). They can be employed as ingredients in nutraceuticals because they are significant sources of nutritional substances, such as micronutrients, fiber, proteins (essential amino acids), and lipids (fatty acids) (Bozan and Temelli 2008). Fruit seeds, which are recovered from agro-industry by-products as food supplements, are not yet as widely available or on the market, which have been advertised for a long time. Currently, a wide variety of fruits seeds that are thrown from the agri-food sector and home, are considered to be potential functional foods and raw materials for formulations in the nutraceutical, cosmetic, and pharmaceutical industries (Alves, Simoes, and Domingues 2021). Whereas, the majority of research papers focus on the oil content and fatty acid profile of fruit seeds, their usage in the production of functional foods and feeds has not received much attention.

Thus, this review aims to provide the nutritional and phytochemical profiling information related to the non-edible fruit's seeds, like apple (*Malus domestica*), apricot (*Prunus armeniaca*), avocado (*Persea americana*), cherry (*Prunus avium*), date (*Phoenix dactylifera*), Jamun (*Syzygium cumini*), litchi (*Litchi chinensis*), longan (*Dimocarpus longan*), mango (*M. indica*) and papaya (*Carica papaya*) (Figure 1), and discuss about the clinical studies conducted on them. Further, this review will also highlight the safety issues and utilization of these non-edible fruit seeds in enriching different food products and animal feed.

## Nutritional and phytochemical profile of selected non-edible fruit seeds

### Proximate composition

The nutritional composition of the fruit seeds, including their moisture, protein, fat, carbohydrate, ash, and fiber contents is shown in Table 1. Mango seed kernels have the highest carbohydrate content of all the fruit seeds and it is possible to use them as foods that provide energy. During times of famine, the kernel starch was consumed as a staple diet in some areas of India (Nithitanakool et al. 2013). Depending on the cultivar and agro-climatic circumstances, apple seeds have greater protein content (33.79–49.55%), followed by cherry seeds (37.95%), and papaya seeds (21.9–31.9%) (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). The date seed has the highest fiber content (22.5–80.2%). According to studies, the dates have more fibers than cereals (Alkhoori et al. 2022). Date seeds include functional dietary fibers, such as lignin, tannin, hemicellulose and pectin. According to Attia et al. (2021) date seeds had higher fiber content than barley and corn.

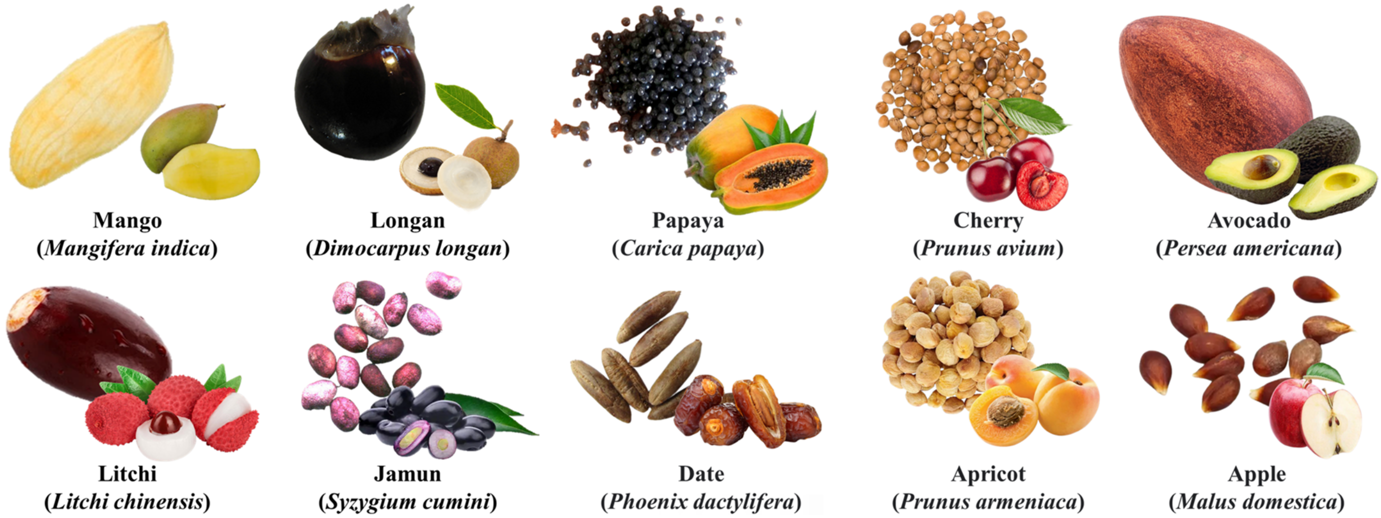


**Figure 1.** Different types of commonly available waste non-edible fruit seeds.

### *Amino acids*

Although mango seed kernels are low in protein, they are high in essential amino acids, including lysine, valine, and leucine as shown in Table 2 (Rai et al. 2020). Longan seeds contain 4.88 g of total amino acids per 100 g of dry weight, with 1.72 g/100g of essential amino acids which accounts to 35.25% of total amino acids present in it (Li, Wu, and Huang 2012). In general, the amino acid concentration of papaya seed meal may depend on its ripening stages. Previously, Oyeleke et al. (2017) observed that the levels of amino acids, in particular lysine and methionine, were higher in the mature, unripe papaya seed than in the ripe papaya seed. When compared to ripe papaya seed, the amount of lysine and methionine in the seed of an over-ripe papaya was found low (Oyeleke et al. 2017). Orange and papaya seeds showed more total essential amino acids when compared to watermelon, guava, orange, pear, and apple seeds. Besides this the dispensable amino acids were found higher in the apple seeds (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Methionine, leucine, phenylalanine, isoleucine, lysine, tyrosine, threonine, cystine, and valine were the essential amino acids (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022).

The *in-vitro* protein digestibility for apple seed was found to be 79.45%, while the scores for the amino acids' isoleucine, leucine, methionine, lysine, phenylalanine, tyrosine, valine, and threonine, were 78.10, 140.00, 41.82, 58.10, 150.36, 88.29, 93.33 and 64.00, respectively (El-Safy, Salem, and Abd El-Ghany 2012). Despite the fact that there has been very few research on the protein profile of apple seeds, it is reported that they contain a balanced number of essential amino acids, making them a suitable source of protein and a possible component in the development of protein-rich food products (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022).

### *Vitamins*

Jamun seeds are rich in water-soluble vitamins (ascorbic acid, pantothenate, and niacin) in addition to folic acid, biotin and ergocalciferol as shown in Table 3. Vitamins B3, C, and A were reportedly present in jamun seeds (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Retinol was shown to be present at 3 IU/100g among the fat-soluble vitamins (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). $\alpha$-Tocopherol is widely distributed in nature and has the ability to transform into vitamin E (Siddiqui et al. 2023). In the oil of apricot seed, $\alpha$, $\beta$ and $\gamma$ tocopherols are found in significant amounts and are responsible for its stability. Because of these nutrients, apricot oil is an excellent source of active vitamin E molecules and a desired ingredient for functional foods (Górnaś et al. 2015; Matthäus, Özcan, and Al Juhaimi 2016). In a comparative study based on the extraction method by Uluata (2016), the total tocopherol contents, comprising the $\alpha$, $\beta$, $\gamma$ and $\delta$ micronutrients of tocopherol, were compared and the cold press extraction method of apricot seed was found to preserves more tocopherol than the solvent extraction method. Similar to that, the $\beta$-carotene in apricot seed flour acts as a precursor to vitamin A (Siddiqui et al. 2023). The health of the blood vessels, eyesight and immune system are enhanced by the vitamins A, E, and C present in avocado seed's (Bangar, Chaudhary, et al. 2022; Bangar, Dunno, et al. 2022). In contrast, complex B vitamins plays a significant role in relaxing the nervous system, stimulating cognitive function and metabolism, and enhancing the blood circulation (Bangar, Chaudhary, et al. 2022; Bangar, Dunno, et al. 2022).

### *Minerals*

The absence of one or more key minerals affects two thirds of the world's population (Punia and Kumar 2021). Table 4 illustrates the highest concentrations of potassium (K),

**Table 1.** Proximate composition in non-edible fruit seeds.

| Mango (%age) | Longan (%age) | Papaya (%age) | Litchi (%age) | Jamun (%age) | Date (%age) | Cherry (%age) | Apricot (%age) | Avocado (%age) | Apple (g/100 g) | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Carbohydrates (78.2); Crude fat (7.8); Moisture (5.1); Crude protein (4.6); Ash (2.1); Crude fiber (2.1) | Moisture (7.40); Ash (1.73); Protein (7.17); Fat (0.23); Fiber (7.89); Carbohydrates (75.57) | Crude protein (29.1-31.9); Crude ash (9.94-11.5); Crude fat (29.4-31.6); Crude fiber (7.80-9.40) | Moisture (12.65); Ash (1.53); Protein (4.56); Fat (0.40); Fiber (9.98); Carbohydrates (70.88) | Moisture (9.34–16.34); Carbohydrates (31.62–41.4); Total dietary fiber (2.3–16.9); Ash (2.18); Crude protein (1.97–8.5) | Protein (2.3–6.4); Fat (5.0–13.2); Ash (0.82–1.14); Carbohydrates (2.43–4.65); Di eatery fibers (22.5–80.2) | Moisture (8.92); Ash (3.19); Protein (37.95); Fat (40.37); Fiber (10.73); Carbohydrates (7.76) | Protein (14.6–27.1); Carbohydrates (17.5–35.6); Crude fiber (11.85–13.6); Moisture content (27.4–38.8) | Moisture (8.6); Fat (14.1); Fiber (7.1); Ash (2.4); Protein (23); Carbohydrates (44.70) | Moisture (3–18.03); Protein (33.79–49.55); Fat (10.1–29.4); Fiber (3.92–20.6); Ash (3.66–5.20); Carbohydrates (23.50–24.0) | Wisitsak et al. (2012); García-Aguilar et al. (2015); Golshan, Dahdivan, and Ardakani (2017); Bahru, Tadele, and Ajebe (2019); Sugiharto (2020); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); García-Mahecha et al. (2023); Siddiqui et al. (2023) |

**Table 2.** Availability of amino acids in different non-edible fruit seeds.

| Mango (g/100 g) | Longan (mg/100 g) | Papaya (g/100 g) | Litchi | Jamun | Date (g/100 g) | Cherry (mg/g) | Apricot | Avocado | Apple (g/100 g) | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Leucine (8.4), isoleucine (3.23), methionine (1.04), phenylalanine (4.46), lysine (3.13), threonine (2.04), tyrosine (3.17), cystine (2.3), aspartate (6.33), glutamate (13), serine (2.93), proline (3), glycine (3.5), alanine (6.4), histidine (2.31), arginine (5.17), valine (3.8) | Leucine (2.86), isoleucine (190.67), methionine (61.19), phenylalanine (321.74), lysine (227.56), threonine (383.15), tyrosine (241.27), cystine (21.81), aspartic acid (441.63), glutamic acid (591.72), serine (271.50), proline (278), glycine (344.64), alanine (229.26), histidine (319.35), arginine (416.61), valine (251.67) | Leucine (7.78), isoleucine (3.09), methionine (1.30), phenylalanine (3.38), lysine (4.21), threonine (2.85), tyrosine (2.06), cystine (1.14), aspartic acid (7.05), glutamic acid (12.4), serine (3.01), proline (2.13), glycine (4.26), alanine (3.22), histidine (2.21), arginine (6.44), valine (2.25) | NR | NR | Glutamic acid (16.44), phenylalanine (5.93), leucine (6.10), aspartic acid (1.72), alanine (1.2), tyrosine (1.2), lysine (1.1) | aspartic acid (112.29), glutamic acid (256.84), serine (32.84), histidine (21.60), glycine (37.43), threonine (52.85), arginine (84.24), alanine (41.47), tyrosine (48.75), methionine (8.93), valine (45.48), phenylalanine (48.64), isoleucine (39.17), leucine (75.10), lysine (8.85) | NR | NR | Leucine (6.72), isoleucine (3.28), methionine (0.92), phenylalanine (4.21), lysine (2.44), threonine (2.56), tyrosine (3.62), valine (3.92), cystine (1.44), aspartic acid (8.21), glutamic (18.62), serine (3.59), proline (4.88), glycine (5.09), alanine (3.87), histidine (2.12), arginine (11.82) | Li, Wu, and Huang (2012); García-Aguilar et al. (2015); Rai et al. (2020); Sugiharto (2020); Alkhoori et al. (2022); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022) |

Abbreviation: NS: not reported.

**Table 3.** Vitamins in non-edible fruit seeds.

| Mango (mg/100 g) | Longan | Papaya (mg/100 g) | Litchi | Jamun (mg/100 g) | Date | Cherry (mg/100 g) | Apricot (%age) | Avocado (mg/100 g) | Apple | References |
|---|---|---|---|---|---|---|---|---|---|---|
| K (0.59), E (1.3), C (0.56), B6 (0.19), B2 (0.03), B12 (0.12), B1 (0.08), A (15.27 IU) | NR | E (4.09), B2 (0.02), B1 (0.03), B3 (0.11), A (135 IU), C (14.7 IU) | NR | C (1.84-35.75), B5 (0.09), niacin (0.09), A (3 IU), B3 (0.09), C (0.21) | A (NS), B1 (NS), B2 (NS), C (NS), E (NS), K (NS) | E (4.1) | E (0.003-0.040), B17 (0.003-0.0058), A (0.010- 0.022) | A (10), B1 (0.33), B2 (0.29), B3 (0.06), C (97.8), E (0.12) | C (NS), B6 (NS), E (NS) | García-Aguilar et al. (2015); Rai et al. (2020); Sugiharto (2020); Alkhoori et al. (2022); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); Bangar, Chaudhary, et al. (2022); Bangar, Dunno, et al. 2022; Siddiqui et al. (2023) |

Abbreviations: NS: not specified; NR: not reported.

**Table 4.** Minerals in non-edible fruit seeds.

| Mango (mg/100 g) | Longan (mg/Kg) | Papaya (mg/100 g) | Litchi (%age) | Jamun (µg/g) | Date (%age) | Cherry (mg/100 g) | Apricot (%age) | Avocado (mg/100 g) | Apple (mg/100 g) | References |
|---|---|---|---|---|---|---|---|---|---|---|
| Na (21.0), K (22.3), Ca (111.3), Mg (94.8), Fe (11.9), Zn (1.10), Mn (0.04) | Cu (7.9), Fe (12), Mn (14), Na (54), Zn (14), Ca (0.13), K (0.41), Mg (0.16), P (0.16) | Ca (681), Mg (424), P (116), Fe (5.80), Na (23.4), Mn (1.11-1.27), Cu (0.05-0.19), Pb (0.00010- 0.00013) | Mg (0.28), Ca (0.21), P (0.11) | Cu (4.64-21.30), Fe (1.40-42), Zn (0.09-8.69), Mn (4.00-10.44), Na 23.80-438.60), K (130.50-6064.60), Mg (0.10-1116), Pb (6.6), Ca (6.51-1358.60) | K (0.175-0.240), Mg (0.058-0.090), Ca (0.014-0.034), P (0.110-0.134), Na (0.008-0.013) | Ca (192.30), Fe (9.49), Mg (249.15), P (439.0), K (873.22), Zn (3.40), Na (82.98) | Ca (0.0042), Fe (0.0076), P (0.0028), Na (0.001), Mg (0.003), Cu (0.007), Mn (0.001) | Ca (0.82), Zn (0.18), K (4.16), Na (1.41), P (0.09), Fe (0.55), Cu (0.01) | Ca (210), Mg (510), Na (214.1), K (650), P (666.5), Fe (27.1) | Li, Wu, and Huang (2012); García-Aguilar et al. (2015); Bahru, Tadele, and Ajebe (2019); Rai et al. (2020); Sugiharto (2020); Punia and Kumar (2021); Alkhoori et al. (2022); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); Siddiqui et al. (2023) |

**Table 5.** Polyphenols in non-edible fruit seeds.

| Class | Mango | Longan | Papaya | Litchi | Jamun |
|---|---|---|---|---|---|
| Flavonoids | Quercetin, Ellagic acid | NR | Quercetin-3-Kaempferol-3-glucoside, galactoside, | Procyanidin D, proanthocyanidin B2, proanthocyanidin B4, epicatechin, 2a,3aepoxy-5,7,30 ,40-tetrahydroxyflavan-(4b8)-epicatechin, -tetrahydroxyflavan-(4a-8-epicatechin), 2a,3a-epoxy-5,7,30,40-tetrahydroxyflavan-(4b-8-catechin), pinocembrin-7-neohesperidoside, pinocembrin-7-rutinoside, litchioside D, (-)-pinocembrin 7-O-neohesperidoside, pinocembrin 7-O-rutinoside, (-)-taxifolin 40-O-β-D-glucopyranoside, phlorizin, naringin, kaempferol 7-O-neohesperidoside, tamarixetin 3-O-rutinoside, narirutin | Epicatechin, kaempferol, quercetin, catechin, |
| Phenolic acids | Gallic acid, salicylic, p-hydroxybenzoic, vanillic, protocatechuic, caffeic acid, syringic acids, cinnamic acid, | Gallic acid, ellagic acid, ethyl gallate, | Caffeic acid, p-coumaric acid, p-hydroxybenzoic acid, ferulic acid, | Protocatechuic acid coumaric acid, | p-coumaric acid, gallic acid, ellagic acid, ferulic acid, caffeic acid, chlorogenic acid |
| Tannin | Gallotannin, condensed tannins, ellagitannin, complex tannins | NR | NR | NR | Tannic acid |

Abbreviation: NS: not reported.

calcium (C), magnesium (Mg), and phosphorus (P) in longan seeds. Chinese chestnut (*Castanea mollissima*) and pinenut kernels are used as comparison for the mineral content of longan seeds (Li, Wu, and Huang 2012). The findings indicate that while the amount of K is equal, the amounts of Ca, Mg, P, and Zn in longan seeds are respectively 4.3, 2.7, 1.8, 1.3, and 1.2 times more than present individually; in contrast, the amount of Mg is the same as in pinenut kernels, and Ca is 1.6 times upon drying (Li, Wu, and Huang 2012). K is the primary mineral element present in jamun seed, followed by vitamin C (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). In a study conducted by Attalla and Harraz (1996) the seeds of 11 date cultivars in the Qassim region of Saudi Arabia had shown trace quantities of phosphorus (0.19-0.26%). Another element that could be present in date seeds is selenium. Ten date types produced in Saudi Arabia exhibited selenium levels between 1.48 and 2.96 mg/g (Al-Showiman, Al-Tamrah, and BaOsman 1994). Some date varieties contain high selenium contents, which may be associated with the selenium level of the soil (Golshan et al. 2017).

In comparison to peanuts, raw black cherry seeds contain more sodium, calcium, iron, potassium and magnesium. However, the content of Fe, K, and Na was higher than that of almonds. Furthermore, black cherry seeds have higher potassium content ($873.22 \pm 12.64$ mg/100 g) compared to peanuts and almonds (García-Aguilar et al. 2015). In a study conducted by Siddiqui et al. (2023) high amounts of minerals Mg and K as well as various vitamins can be found in apricot kernel oil. Jaafar (2021) demonstrated highest concentration of K in apricot seed flour as compared to apples, oranges, paprika, and guavas seeds. In addition to this, apricot seed flour contained significant amounts of Fe, K, Ca and Na (Siddiqui et al. 2023). El-Safy, Salem, and Abd El-Ghany (2012) reported high concentrations of Ca, K, phosphorus, Fe, Mg, and Na in apple seeds. Apple seed flour, according to Yu et al. (2007), contained calcium (270 mg/kg), iron (110 mg/kg), zinc (44 mg/kg), potassium (650 mg/kg), copper (2 mg/kg), manganese (4.6 mg/kg), and magnesium (510 mg/kg).

## *Phytochemicals*

Most bioactive substances are distinct secondary metabolites with antimicrobial, antioxidant, anti-inflammatory and anticarcinogenic properties and are present in modest quantities in fruits, vegetables, nuts and cereals. Bioactive substances are grouped as essential (minerals and vitamins) and non-essential (flavonoids, polyphenols, phytosterols, glucosinolates, carotenoids, saponins, essential oils and alkaloids) (Rodríguez García and Raghavan 2022). They are recognized as being good for human health and can be extracted and used as an antibacterial or antioxidant agent across many sectors. The high content of carotenoids and polyphenols in

| Date | Cherry | Apricot | Avocado | Apple | References |
|---|---|---|---|---|---|
| Rutin, luteolin quercetin | Catechin | Epicatechin, kaempferol-3-O-glucoside, quercetin, rutin, quercetin-3-galactoside catechin | Catechin, rutin, (epi) catechin, kaempferol | Catechin, quercetin, epicatechin, phloridzin, procyanidin B2 | Kadiri et al. (2017); Afonso et al. (2020); Punia and Kumar (2021); Setyawan, Sukardi, and Puriwangi (2021); Akhone et al. (2022); Alkhoori et al. (2022); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); Szabo et al. (2022); Tacias-Pascacio et al. (2022); García-Mahecha et al. (2023) |
| Chlorogenic acid, syringic acid, p-coumaric acid, vanillic acid ferulic acid, gallic acid, caffeic acid, | Gallic acid, p-coumaric acid protocatechuic acid, | Chlorogenic acid, gallic acid | Chlorogenic acid, caffeic acid, vanillic acid, ferulic acid, | Protocatechuic acid, chlorogenic acid, | Kadiri et al. (2017); Tang et al. (2019); Afonso et al. (2020); Rai et al. (2020); Punia and Kumar (2021); Setyawan, Sukardi, and Puriwangi (2021): Akhone et al. (2022); Alkhoori et al. (2022); Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); Szabo et al. (2022); Tacias-Pascacio et al. (2022); García-Mahecha et al. (2023) |
| NR | NR | NR | NR | NR | Kumar, Bhardwaj, et al. (2022); Kumar, Hasan, et al. (2022); Kumar, Zhang, et al. (2022); Kumar, Barbhai, et al. (2022); García-Mahecha et al. (2023) |

mango agro-industrial by-products, has led many researchers to focus on the functional properties of these bioactive compounds (Okino-Delgado and Fleuri 2016). Most polyphenol compounds contain glycosides, and all of them have at least one aromatic ring and one hydroxyl group in their structure. When any diseases, predators and parasites attack a plant then soluble polyphenols help against them and even provide defence against the UV rays. Insoluble polyphenols contribute to the structure of the cell wall to which they are covalently bound. They are categorized as phenolic acids like hydroxycinnamic (syringic acids, protocatechuic and vanillic) and hydroxybenzoic acids (chlorogenic, ferulic, sinapic acids and p-coumaric), and flavonoids (anthocyanidin, flavanones, flavonols, isoflavones, and flavones). According to research by Ekorong Akouan Anta et al. (2018) and Rodríguez García and Raghavan 2022, polyphenols are found as polymers in plants like tannins (ellagitannins, gallotannins, condensed, and complex tannins) and lignin. The high polyphenolic content of mango seed kernels accounts for a higher level of antioxidant activity than that of jackfruit, avocado and tamarind (Table 5) (Rai et al. 2020). Using high-performance liquid chromatography-diode array detection-electro-spray ionization mass spectrometry (HPLC-DAD-ESI-MS/MS), Kadiri et al. (2017) identified and quantified six phenolic compounds from the papaya seed, including p-hydroxybenzoic acid, p-coumaric acid, caffeic acid, quercetin-3-galactoside and ferulic acid. Ferulic acid has been reported as the predominant phenolic compound followed by p-coumaric acid and caffeic acid. In recent years, research trends have changed toward the value-added use of fruit processing waste, because of government policies addressing environmental pollution and increasing awareness of their nutritional benefits (Punia and Kumar 2021). Since phenolic compounds (PCs) in litchi seeds are particularly effective at controlling range of physiological and metabolic processes, they are regarded as a superior source of PCs for the human body (Punia and Kumar 2021). Procyanidins (flavan-3-ols) are abundant in litchi seeds and comprise the majority of their trimers and dimers (Lv et al. 2015). With the help of high-resolution electrospray ionization mass spectrometry (HRESIMS) and nuclear magnetic resonance (NMR) seven flavonoid glycosides from litchi seeds were obtained (Xu et al. 2011). Through high-performance liquid chromatography and column chromatography flavonone triglycosides i.e., litchioside D (1), tamarixetin 3-O-rutinoside, (-)-pinocembrin 7-O-neohesperidoside (2), phlorizin, taxifolin 4-O-D-glucopyranoside, kaempferol 7-O-neohesperidoside, and (-)-pinocembrin 7-O-rutinoside had been identified (Xu et al. 2011).

Tannic acid (188.5 mg/g) was found to be the most prevalent phenolic acid in the dried seed extracts of jamun seed, followed by gallic acid (90.8 mg/g), ellagic acid (36 mg/g), and caffeic acid (26.07 mg/g) (Balyan and Sarkar 2017). Despite catechin which was reported to be the most prominent flavonoid compound in the extract of jamun seed, the gallic acid was revealed to be the primary contributor to the antioxidant activity. When compared to other fruits like grapes and nut seeds, date seeds were shown to have higher amounts of total polyphenols (Habib et al. 2014).

Date seeds contain distinct phenolic acids, with p-coumaric acid having the highest concentration (109.87–141.72 mg/100 g), followed by caffeic, chlorogenic, ferulic, gallic, syringic, and vanillic acids (Bouhlali et al. 2020). Additionally, rutin (71.74–86.32 mg/100 g) appears to be the most abundant flavonoid in date seeds, followed by quercetin (23.71-34.06 mg/100 g) and luteolin (9.17–13.24 mg/100 g), based on HPLC analysis using a diode-array detector (DAD). Apricot cultivars exhibited different phenolic chemicals depending on the environmental conditions, region and including irrigated and dry land conditions (Siddiqui et al. 2023). An apricot cultivar known as Turkey is believed to have one of the best and most prevalent phenolic compounds (Sartaj et al. 2015). A total of 1277 g of gallic acid extract/100 g of dry weight to seed kernel was used to calculate the phenolic content and the average values of the total phenolic contents in various apricot seed varieties were, about 267 g of gallic acid extract/100 g of dry weight (Siddiqui et al. 2023). Additionally, studies were conducted to examine the total phenolic contents of bitter and sweet apricot kernels and the results showed the difference in total phenolic component concentrations of the bitter and sweet apricot kernels (Siddiqui et al. 2023). The total phenolic content of sweet kernels is higher than that of bitter apricot seed kernels. In the experiment, total flavonoid content was also determined; and was found to be 153.1 to 0 mg CE/100 g dry weight. According to Rampáčková et al. (2021), the average amount of total flavonoids was observed to be 22 mg CE/100 g of dry weight.

Total phenolic compounds (TPCs) were present in defatted apple seeds from 12 different cultivars of cider and dessert apples at concentrations ranging from 18.4 to 99.8 mg/g. Phloridzin (3256.3–22351.8 mg/kg of defatted dry matter) predominated among all TPCs, and it is well-known to cure obesity and type II diabetes mellitus (Fromm et al. 2012). Duda-Chodak, Tarko, and Tuszyński (2011) reported that apple seeds with higher polyphenols than their peel and pulp, particularly phloridzin (256.97–438.89 mg/100 g), demonstrating the highest antioxidant activity (Idared seeds: 3000 mg Trolox/100 g of fresh weight (f.w). Crab apple, often known as wild apple, (*Malus baccata* (Lin.)) contained 112.23 1.1 mg of retinol equivalent (RE)/g and 154.16 0.8 mg of total flavonoids in the seeds (Dadwal et al. 2018).

Red delicious (*M. domestica*) and wild crab (*M. baccata*) apple seeds' total phenolic content was 1.78 mg/g on a fresh weight basis, but showed an elevation of 15.92–14.56 mg/g, on a dry weight basis. Similarly, ascorbic acid content was reported as 11.66–19.68 mg/g on fresh weight basis and 104.13–161.27 mg/g on a dry weight basis (Sharma and Nath 2016). In a study by Madrera and Valles (2018) the defatted apple seeds were found to contain condensed tannins (2.4–3.6 mg of gallic acid per gram of defatted matter), extractable polyphenols (2.7–6.7 mg of gallic acid per gram of defatted matter), and hydrolyzable tannins (34.5–44.4 mg of gallic acid per gram of defatted matter). Hydroxycinnamic acid derivatives, 5-caffeoylquinic acid (chlorogenic acid) and phloretin-2′-xyloglucoside were also reported in apple seeds (Fromm et al. 2012).

## Clinical studies of non-edible fruit seed extracts

### Humans

The anti-hyperlipidemic effects of Maghz-e-Jamun (*Eugenia jambolana*) on patients with intermediate hyperglycemia were investigated by Parveen, Khan, and Khan (2020). According to American Diabetes Association (ADA) criteria, prediabetic patients were randomized into two groups and supplemented with 4.5 gm of jamun seed powder daily in the form of capsules in group A, while group B received placebo capsules. At the beginning and after 84th day of treatment, lipid profiles were assessed. The lipid profiles of the prediabetic participants have improved significantly, with particular emphasis on total cholesterol (which decreased from $266.47 \pm 62.92$ to $216.058 \pm 40.14$ with a *p*-value of 0.008**) and low-density lipoprotein (LDL) which increased from $189.23 \pm 55.07$ to $138.58 \pm 34.86$ with a *p*value of 0.003**. The impact of jamun seed powder on dyslipidaemia (DM) was investigated by Sidana et al. (2016) in type 2 diabetes mellitus patients. They were placed into two groups at random; group A received 10 g/day of jamun seed supplementation, whereas, group B received placebo powder. At the baseline, as well as at days 30, 60, and 90, lipid profiles were noted and after 60th day of supplementation, improvement in dyslipidaemia was observed. Low-density lipoprotein cholesterol (LDL-c) levels decreased by 10.29% and 14.50%, decreases in total cholesterol by 10.55% and 15.79%, mean triglyceride levels by 8.28% and 13.66%.at the 60th and 90th days and levels of very low-density lipoprotein cholesterol (VLDL-c) decreased by 9.38%, 12.90%, and 20.69% at the 30th, 60th, and 90th days. After 60 and 90 days of supplementation with *S. cumini* seed powder, high-density lipoprotein-cholesterol (HDL-c) significantly increased by 11.11% and 13.89% in males and 10.81% and 16.21% respectively in females.

The impact of Ajwa date seed powder on the lipid profile of human serum was investigated by Jubayer, Kayshar, and Rahaman (2020). In the intervention group, the Ajwa date seed powder resulted in reductions in total cholesterol (TC), LDL cholesterol, and triglycerides (TG) levels of 19.4%, 22.5%, and 25.78% as well as an increase in HDL levels of 23.81%. A hypothesis that sours cherry (*Prunus cerasus*) seed extracts (SCE) can alter $CD3^+$ T cell activity for treating inflammatory illnesses was evaluated by Mahmoud et al. (2013). For this study twelve type 2 diabetes (T2DM) patients' peripheral blood mononuclear cells (PBMC) and eight healthy control subjects were cultured for 24 h with 100 ng/mL lipopolysaccharide (LPS) to promote inflammatory signaling, and they were also co-incubated with 0.5–100 mg/mL SCE. Two-color flow cytometry and enzyme-linked immunoassay (ELISA) was used for evaluation of cultures for Interleukin ($IL8^+$) and $CD3^+$, tumor necrosis factor alpha (TNF-$\alpha^+$) cells which express IL-8, and TNF-$\alpha^{+,}$ percent representation of cluster of differentiation ($CD3^+$), and lymphocyte-associated heme oxygenase-1. SCE dosages between 0.5 and 100 mg/mL significantly decreased $CD3^+$, $TNF-\alpha^+$, and $CD3^+$, $IL8^+$ representation from all individuals in cell cultures ($p < 0.05$), with a larger pharmacological effect shown in cells from T2DM patients than from healthy control subjects. The ability of sour cherry seed extract (SCE) to prevent lipopolysaccharide-treated human peripheral blood T cells from producing TNF-α and the chemokine IL8 was also examined by the same group (Mahmoud et al. 2014). Both proteins serve as inflammatory diseases' diagnostic biomarkers and following a 24-h co-culture in lipopolysaccharide and the extract, peripheral blood leukocytes from 11 RA patients and eight healthy control subjects were examined. When compared to cells from healthy persons, cultures from RA patients showed a larger dose-dependent reduction in the expression of the immunophenotypes $CD3^+$, $TNF-\alpha^+$ $CD3^+$ and $IL8^+$. These findings imply that the extract may modulate RA and other inflammatory illnesses by inducing HO-1, which reduces oxidative stress and enhances the control of signaling pathways that promote inflammation.

### *Animals*

Kobayashi et al. (2013) studied the anti-obesity effects of mango seed kernel extract (MSKE-W) with hot water in 3T3-L1 adipocytes and in rats fed on high fat diet induced obesity. Through down-regulation of transcription factors such as PPAR$\gamma$ and C/EBP$\alpha$, a significant reduction in the activity of glycerol 2-phosphate dehydrogenase without inhibiting cellular lipid accumulation and inducing cell cytotoxicity was observed. In the animal model, rats fed on HFD containing 1% MSKE-W gained less weight than rats fed on HFD alone. The visceral fat mass in rats fed on HFD containing 1% MSKE-W tended to be lower than that in rats fed on HFD alone. Rats fed on HFD containing 1% MSKE-W gained less weight than rats, had tendency to lower visceral fat mass than rats fed on HFD alone.

In an animal model of diet-induced obesity, Martinelli et al. (2020) examined the effects of *P. cerasus* L. juice and seeds on liver steatosis. This study examined how tart cherries high in anthocyanins affect the diet-induced obese (DIO) rats. DIO rats were fed a high-fat diet with sour cherry seeds powder (DS), seed powder + juice as supplements (DJS). The DIO rats displayed an increase in insulin, body weight, systolic blood pressure and glycemia after 17 week of feeding. Furthermore, in the DS and DJS groups a decrease in systolic blood pressure, thiobarbituric reactive compounds, triglycerides, and glycemia in the serum was observed.

Takaeidi et al. (2014) studied the paraoxonase and arylesterase activities in hypercholesterolemic rats by administering methanolic date seed extracts (DSE). An increase in serum paraoxonase and arylesterase activity in treated hypercholesterolemic were observed and total antioxidant capacity (TAOC) of serum varied significantly between the hypercholesterolemic and normal diet groups. The presence of natural antioxidants such as phenol compounds in date seed contribute to these positive advantages.

The effectiveness of jamun (*Syzygium cumini*) seed extracts against hyperglycemia was assessed by Raza et al. in 2017. The results of the study showed that, in normal and hyperglycemic rats, glucose level decreased from 7.04% and 14.36% and insulin levels increased by 3.56% and 7.24% respectively. The impact of lychee seed saponins (LSS) on neuroprotection and related mechanisms was examined by Wang et al. (2017). By injecting Aβ25-30 into the lateral ventricle of rats, a rat model of Alzheimer's disease (AD) was established and the impact of LSS on memory and spatial learning using the Morris water maze was assessed. The findings demonstrated that LSS significantly reduced neuronal damage and enhanced the cognitive function in the hippocampus of AD rats *via* suppressing apoptosis. Additionally, LSS raised the ratio of Bcl-2/Bax and protein expression of Bcl-2 while downregulating the protein expression of Bax and mRNA expression of caspase-3.

## Enrichment application of non-edible fruit seeds in food

Since many nutrients, especially micronutrients, are lost during the production process. For instance, the most popular enriched food is white bread, to which certain specialized vitamins are added and after the bleaching process, its levels significantly reduce (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Both fortification and enrichment broadly relate to the addition of nutrients to food (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Agro-industrial waste is now considered to be a fuel source as well as a raw material for biorefineries. In the perspective of recovery and valorization for the sustainable use of various components of the by-products, these are viewed as a source of profit and are value-added in food, pharmaceutical, nutraceutical, chemical, animal feed, and cosmetic sector (Alves, Simoes, and Domingues 2021). Innovative methods are emerging for the management and eco-sustainable use of waste in the fruit processing sectors for the manufacture of jams, purees, juices, muesli, yogurts, canned fruit, snacks, and so on (Alves, Simoes, and Domingues 2021. The leaves of fruit can be used to extract a variety of nutraceuticals or nutrients to enhance meals, create consumable goods for example, teas, create dietary supplements or medicinal formulations (anti-inflammatories, etc.). However, the fruits' seeds are a great source of biologically important compounds. Figure 2 summarizes the role of non-edible fruit seeds in development of various food product. Additionally, the level of incorporation of seeds has a significant impact on the characteristics of the food products.

### *Cereal-based foods*

Cereal-based items, such as bread, cookies, cakes, and noodles (Figure 2) are an essential component of the daily diet as they offer significant amount of carbohydrates and protein but lack micronutrients (minerals and vitamins), fiber and phytochemicals. The growing consumer desire for nutritious foods offer additional functional health components to basic nutrition (Bangar, Chaudhary, et al. 2022; Bangar, Dunno, et al. 2022). In cereal-based products, non-edible fruit seeds are used as a functional ingredient in the form of powder and extract (Table 6).

According to Dhen et al. (2018), enriched bread made with apricot kernel flour (AKF) has low carbohydrate content and the bread quality was slightly affected by the partial replacement of wheat flour (WF) with AKF up to 12%. Bouaziz et al. in 2020 enhanced wheat bread by adding hemicellulose extracted from date seed extracted (DSH). The results of the study showed that adding 0.75% DSH significantly enhanced the dough's alveograph profile, volume of bread (24.22%), texture profile (by reducing the hardness and chewiness by 41.54% and 33.81%) and overall higher acceptance. By substituting wheat flour with the seeds of six different date fruit varieties: Khalas, Fard, Khinaizi, Zahidi, Sukkary, and Shaham an increase in the antioxidant value of cookies was observed (Najjar et al. 2022). Three levels of the sample to solvent ratio (5:1, 10:1, and 15:1) were used for the extraction of date seed powder (DSP). Cookies were made using two types of flour (white and whole wheat) and three substitution levels of wheat flour (2.5, 5.0, and 7.5%, w/w) by DSP and were baked at 180 and 200 °C. The composite cookies showed higher antioxidant activity than the control samples and were found to contain considerable amounts of TPC and flavonoids.

The multigrain cookies supplemented with 2% mango kernel powder have been produced by Aamir et al. (2022). The sensory evaluation of the product showed an acceptable mango taste and flavor, the highest sensory score, and improved results for antioxidant and physicochemical analysis. Wheat cookies prepared by Jiang et al. (2022) by adding papaya seed (PS) in the range of 2–10% to biscuits increased the ability to absorb nitrite ($NO_2^-$) ion, bile acid and cholesterol and greatly improved nutritious components, polyphenol compounds, and antioxidant activities. In another study Das et al. (2019) prepared the cake using mango kernel flour (MKF). The majority of the macronutrients in the created cakes increased as the MKF concentration increased, and a cake containing 40% MKF provided approximately 3.6% more energy than a cake containing no MKF. The results of chroma analysis revealed that MKF addition darkened the cakes' crust and crumb colors. The panellist's preference for the 20% MKF-containing cake among the composite cakes was determined by sensory evaluation, and the storage stability test showed that MKF-substituted cakes were more stable than control cakes and can be kept without preservatives for about 7–10 days. A cake was developed by Mahde and Fayed (2022) using apricot seed kernels (ASK) and it has been shown that cakes containing ASK at a

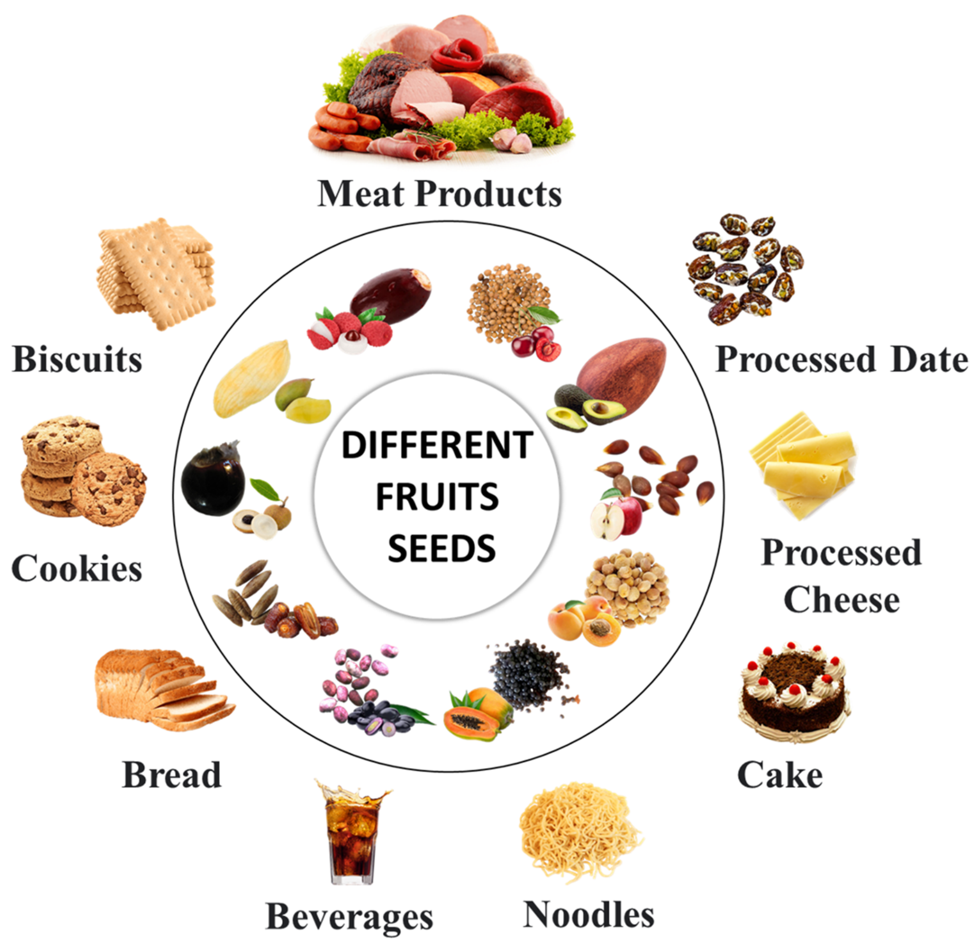


Figure 2. Different non-edible fruits seeds and their application in different food products.

**Table 6.** Application of non-edible fruit seeds in cereal-based products and their quality characteristics.

| Product developed | Country of study | Type of non-edible seed used | Quantity added | Product quality | References |
|---|---|---|---|---|---|
| Biscuit | India | Mango seed kernels | 10–40% | Increase in antioxidant activity, energy, crude fat, crude fiber, minerals (calcium, iron and magnesium) | Kaur and Brar (2017) |
| | Ethiopia | Mango seed kernels | 10–30% | Decrease in emulsion activity and oil absorption with addition of 30% seed kernel powder | Legesse and Emire (2012) |
| | China | Papaya seed | 2–10% | Good overall acceptability, enhancement of polyphenolic content, nutritional composition, antioxidant activities of biscuits with addition of 4% papaya seed powder | Jiang et al. (2022) |
| | India | Jamun seed | 3–12% | Improvement in sensory qualities (taste, color, flavor and overall acceptability) with supplementation of 9% jamun seed powder in biscuits | Kalse et al. (2016) |
| | India | Jamun seed | 6–10% | Excellent appearance, texture, color, flavor and overall acceptability of biscuits added with 8% jamun seed powder | Patil et al. (2014) |
| Cookies | India | Mango seed kernels | 20–50% | Enhancement of phenolic content (22.4 mg GAE/g) of cookies with 30% addition of seed kernel powder | Bandyopadhyay, Chakraborty, and Bhattacharyya (2014) |
| | India | Papaya seed | 1.15–1.63% | Supplementation of cookies with 1.24% of papa seed powder showed maximum overall acceptability | Bhosale and Udachan (2018) |
| | United Arab Emirates | Date seed | 2.5–7.5% | Increase in antioxidant activity, total phenolic content and flavonoids of the composite cookies | Najjar et al. (2022) |
| | India | Jamun seed | 20–40% | Cookies supplemented with 30% jamun seed powder showed good sensory properties (color, appearance, flavor, crispiness, taste and overall acceptability) and storage stability up to 30 days | Thorat and Khemnar (2015) |
| Bread | Serbia | Apple seed cake | 5 and 20% | Cakes supplemented with 20% apple seed powder showed highest total polyphenol content and antioxidant potential; cakes supplemented with 5% apple seed showed good textural and sensory properties | Purić et al. (2020) |
| | India | Mango seed kernels | 5–13% | Bread supplemented with 5% seed kernel powder showed good sensory qualities | Menon, Majumdar, and Ravi (2014) |
| | Tunisia | Date seed | 1–3% | Enhancement of dietary fiber content | Bouaziz et al. (2020) |
| | Tunisia | Apricot seed kernels | 4–24% | Supplementation of 12% apricot kernel flour in bread shows good quality and higher acceptability among consumers | Dhen et al. (2018) |
| | Saudi Arabia | Date seed | 5–15% | 10% date seed powder addition in coarse fraction into bread increases the TDF fiber contents in by four–fold without deleterious effect on bread quality | Almana and Mahmoud (1994) |
| | Iran | Date seed | 1–3% | Reduction of bread staling in breads during 5 days of storage | Hejri-Zarifi et al. (2014) |
| Cake | Bangladesh | Mango seed kernels | 10–40% | Cake with 20% mango kernel flour was the most acceptable with preservatives free storage stability for up to 7–10 days | Das et al. (2019) |
| | Bangladesh | Jamun seed | 10–30% | Cake containing 10% jamun seed flour showed highest acceptability | Marufa, Das, and Iqbal (2019) |
| | Iraq | Apricot seed kernels | 2.5–10% | Cakes with 7.5% addition of apricot seed kernel powder showed highest acceptability | Mahde and Fayed (2022) |

(*Continued*)

Table 6. Continued.

| Product developed | Country of study | Type of non-edible seed used | Quantity added | Product quality | References |
|---|---|---|---|---|---|
| Noodles | India | Jamun seed | 2–10% | Noodles supplemented with 8% jamun seed powder showed highest storability and acceptability with crude protein (10.89%), crude fat (0.60%), crude fiber (1.43%) and ash content of 0.91% | Sood, Bandral, and Kaur (2018) |

Abbreviations: GAE: Gallic acid equivalent; TPC: Total phenolic content; TDF: Total dietary fiber.

Table 7. Application of non-edible fruit seeds in non-cereal-based food products and their quality characteristic.

| Product developed | Country of study | Type of non-edible seed used | Quantity added | Product quality | References |
|---|---|---|---|---|---|
| Beverages | Saudi Arabia | Date seed | 10–60% | 50% acceptability in cappuccino and latte on addition of date seeds | Algarni (2020) |
| | India | Jamun seed | 5–20% | Highest overall acceptability with 15% seed extract | Desai, Kshirsagar, and Sawate (2019) |
| | India | Jamun seed | 1.25 and 5% | Increase in amounts of antioxidants in the juice samples with increase in amounts of dried seed powder | Wasswa, Tumuhimbise, and Acham (2019) |
| Processed cheese | Saudi Arabia | Date seed | 5–20% | Addition of 5% date seed showed highest sensory acceptability | Alqattan et al. (2020) |
| Meat products | China | Litchi seed | 0.1–1.0% | Improvement of meat paste sensory properties during storage period with litchi seed water extract addition | Qi et al. (2015) |
| | Tunisia | Date seed | 3–10% | Insoluble fibers of date seeds showed the higher acceptability in turkey burger samples | Bouaziz et al. (2010) |
| | Thailand | Longan seed | 0.05–0.20% | 0.20% of seed aqueous extract preserved the color of cooked pork patties | Nitteranon and Sayompark (2021) |

concentration of 7.5% are acceptable on the basis of sensory characteristics. The cakes contained more calories, crude fiber, crude fat, and total ash than control samples ($p < 0.01$) and also the calcium, iron, and magnesium concentrations, antioxidant activity (2.5–7.5%) has been reported to be significantly higher.

### *Other food products*

Non-edible fruit seed in the form of juice, puree, powder, and extract have been successfully used in other food products (Figure 2 and Table 7).

Cappuccino and latte beverages were prepared with date seed powder by Algarni (2020). According to the findings, increase in consumer acceptability was reported up to 50% and the sensory evaluation indicated that the prepared beverages i.e., cappuccino and latte were highly acceptable with addition up to 50%. According to Wasswa, Tumuhimbise, and Acham (2019), adding more dried jamun seed powder to the juice resulted in lower sensory acceptability and increase in the antioxidant levels. The antioxidant effects of lychee seed water extract (LSWE) were evaluated by Qi et al. (2015) in raw beef pastes and storage studies were done for a period of 0-15 days at 4 °C. An *in-vitro* 3T3-L1 preadipocyte cell culture was used to examine the cytotoxic and anti-obese effects of LSWE. The outcomes demonstrated that LSWE was efficient and nontoxic in preventing preadipocyte differentiation. The down-regulation of many adipogenesis-specific genes, including C/EBP-α, PPAR-γ, KLF9 and C/EBP-β, C/EBP-δ, were responsible for these effects. Supplementing with LSWE proved successful in delaying the oxidation of meat paste's lipids. The sensory examination of the beef paste revealed that LSWE had no negative effects on its sensory qualities. On the other hand, LSWE considerably enhanced the beef paste's sensory qualities in the final stages of the preservation period. In order to improve the quality of a meat product, insoluble fibers from Tunisian Deglet Nour date seeds were added as insoluble fiber concentration (IFC) at 3%, 5%, and 10% (w/w) to turkey burgers, which had a low-fat and high-fiber level (Bouaziz et al. 2020). Also, with higher incorporation levels compared to the control sample, hardness and adhesiveness values increased considerably ($p < 0.05$) and the Turkey burger samples supplemented with 5% IFC scored higher ($p < 0.05$) in overall acceptability in the sensory analysis.

## Enrichment applications of non-edible fruit seed in animal feed

To increase the economic effectiveness of animal production, selection is ongoing among farm animal populations (Svitáková et al. 2014). Numerous internal and environmental parameters, including nutrition without a doubt, have an impact on animal productivity. Given that they improve a variety of critical physiological functions in animals, phytogenic additions offer a viable alternative (Karásková, Suchý, and Straková 2015). The supplements that improve the animal health, quality of feed and animal products may contain phytogenic feed additives because of their very effective constituents. Sensory additives (feed additives affecting the sensory properties of animal products), zootechnical additives (immunomodulators, digestive stimulants, growth promoters of non-microbial origin, substances increasing performance or quality of animal products, etc.), nutritional additives (vitamins, minerals, plant enzymes, etc.) and technological additives (antioxidants, substances reducing mycotoxin contamination of feeds, etc.), can all be categorized under this category. The Tables 8 and 9, summarizes the role of non-edible fruit seeds in the development of functional feeds for chicken and fish.

### Chicken and fish

The impact of raw and fermented sour cherry kernels by *Aspergillus niger* on broiler chicken carcass characteristics, meat quality and growth performance were examined by Gungor and Erener (2020). Although chicken fed 2 and 4% RC had decreased ($p<0.01$) body weight (BW), body weight gain (BWG), and feed intake (FI) from day 1 to day 42, compared with that of the birds in the control group, dietary RC enhanced ($p<0.001$) the feed conversion ratio (FCR) at the 1% inclusion level. From day 22 to day 42, dietary FC at a 1% inclusion level increased ($p \leq 00.05$) BWG and ($p<0.001$) FCR. In contrast to the control group, 4% dietary FC had a negative impact on FI, BW, FCR, and BWG ($p<0.01$). The findings showed that RC can be added to broiler diets up to 1% level without negatively affecting growth performance, and FC can be utilized in broiler nutrition up to 2% level. Farias et al. (2021) examined how broiler chicken carcass features, performance, blood parameters and relative weight of the digestive system segments, were affected by the addition of various quantities of ethanolic extract of mango seed (EEMS). Treatments included diets with additions of 200 mg/kg of the antioxidant butylated hydroxytoluene in 200, 400, 600, 800, or 1000 mg/kg of EEMS, and diets without antioxidant addition (control). The carcass features, performance metrics, and relative weight of the digestive tract segments did not significantly differ across the treatments. The broilers fed the control food had considerably higher levels of total cholesterol than the animals given diets containing EEMS. Sugiharto, Pratama, and Yudiarti (2021) examined the effects of sprouted-papaya seed meal (SPSM) on the carcass characteristics and growth of broilers. Feeding SPSM up to 5% did not affect the feed intake and growth of broilers ($p>0.05$). At 5%, SPSM decreased the amount of breast meat and affected the feed conversion ratio ($p<0.05$). Papaya seed meal at the same percentage decreased weight increase, final body weight, and cumulative feed consumption while SPSM at 2.5% had no negative effects ($p>0.05$). Therefore, SPSM can be added to broiler rations up to 2.5% without having a negative impact on the birds' growth, feed intake, FCR, or carcass characteristics.

The implications of longan seed (LS) powder on Nile tilapia (*Oreochromis niloticus*) immunological response, growth performance and immune-antioxidant associated gene expression were examined by Wannavijit et al. in 2022 (Table 9). The basal diet (control without LS) and the basal diet containing 10 (LS10), 20 (LS20), 40 (LS40), and 80 (LS80) g/kg LS were both fed to 300 fish ($13.82 \pm 0.06$ g) for eight weeks using three replications of a completely randomized design were used and after 4th and 8th weeks of feeding, the growth performance and immunological response were assessed, while the gene expressions were detected at the completion of the feeding study. As compared to the control group, the results showed that feeding Nile tilapia with LS may considerably ($p>0.05$) improve weight gain, specific growth rate, and FCR. After 4th and 8th week of feeding LS20 diets an increase in skin mucus peroxidase activity (MPA), serum lysozyme activity (SLA), serum peroxidase activity (SPA), skin mucus lysozyme activity (MLA), up-regulation of antioxidant and immune related gene expressions (IL1, IL8, LBP, GSTa, GPX, and GSR) in the liver and intestine was observed. The performance of African catfish (*Clarias gariepinus*) fingerlings fed diets containing various levels of fish meal replacement with pawpaw seed powder meal (0, 20%, 40%, 60%, and 80%) was investigated by Irabor, Ekokotu, and Nwachi (2016) over the period of a six-week feeding trial. Fish were weighed every week and fed at a rate of 3% of their body weight per day and assessed

**Table 8.** Application of non-edible fruit seeds in chicken feed and their health characteristic.

| Chicken condition | Country of study | Type of non-edible seed used | Quantity added | Health characteristics | References |
|---|---|---|---|---|---|
| One day old broiler | Nigeria | Avocado seed | 0.5–1.5% | Incorporation of 1.5% avocado seed powder showed significant difference in the WBC, neutrophils, platelets and lymphocytes | George, Kingsley, and Ekine (2020); George, Allison, and Ekine (2020) |
| One day old broiler | Nigeria | Avocado seed | 0.5–1.5% | Increase in the final weight after incorporation of 0.5% avocado seed powder | George, Kingsley, and Ekine (2020); George, Allison, and Ekine (2020) |
| One day old Ross 308 mail broiler | Turkey | Cheery seed kernels | 1–4% | Improved of feed conversion ratio upon feeding 1% powder | Gungor and Erener (2020) |
| One day old MB202 Lohmann broiler | Indonesia | Date seed | 2.5–10% | Increase in digestibility of protein and body weight with 10% addition of date seed flour | Sholichatunnisa et al. (2022) |
| Two hundred old broiler | India | Mango seed kernels | 2.5–10% | 10% kernels powder showed minimum feed cost / kg weight gain of broilers | Kumar and Singh (2010) |
| Twenty-eight days old Gimmizah cockerels | Giza | Mango seed kernels | 10–20% | Significant decrease in consumption and improvement in feed conversion with 10% kernels powder | El. Moustafa et al. (2019) |
| Twenty weeks old Sasso hens and males | Lome-Togo | Papaya seed | 0.5% | Increase in weight, feed conversion ratio, heavier eggs, higher ratio of albumen with papaya seed powder addition | Dassidi et al. (2020) |

Abbreviation: WBC: white blood cell.

**Table 9.** Application of non-edible fruit seeds in fish feed and their health characteristics.

| Fish condition | Country of study | Type of non-edible seed used | Quantity added | Health characteristics | References |
|---|---|---|---|---|---|
| Healthy Nile tilapia fingerlings (*Oreochromis niloticus L.*) | Saudi Arabia | Date seed | 1–3% | Improvement in hemoglobin, hematocrit levels and significant decrease in blood glucose levels with addition of 1% date seed powder | Mathew, Alsaqufi, and Al-Ngada (2020) |
| Healthy Common carp (*Cyprinus carpio* L.) | Iraq | Date seed | 0.25–0.5% | High protein efficiency ratio, weight gain and specific growth rate with 0.5% date seed powder addition | Ahmed et al. (2017) |
| Healthy Nile tilapia (*Oreochromis niloticus L.*) | Thailand | Longan seed | 1–8% | 20 g/kg longan seed powder improved the growth performances, weight gain, skin mucus and serum immune responses, feed conversion ratio, enhancement of antioxidant and immune gene expressions, can be used as functional feed additive and immunostimulant in a biofloc system | Wannavijit et al. (2022) |
| Healthy juvenile (*Labeo senegalensis*) | Nigeria | Mango seed kernels | 10–30% | Incorporation of mango seeds into diets of juvenile *L. senegalensis* showed good health of the fish without significant depression of growth | Omoregie (2001) |
| Healthy juvenile (*Clarias gariepinus*) | Nigeria | Mango seed kernels | 25–100% | Increase in specific growth rate and feed conversion ratio with 75% mango seed kernels inclusion | Falaye, Sule, and Kourouma (2021) |
| Healthy Nile tilapia (*Oreochromis niloticus L.*) | Nigeria | Papaya seed | 0.2–0.8% | Weight gain and increase in masculinization percentage with 4% papaya seed meal inclusion | Ugonna et al. (2018) |

for specific growth rate, weight gain, food conversion ratio, protein efficiency ratio, and mortality. Hence, it is inferred that pawpaw seed powder meal can substitute fish meal in the diet of *C. gariepinus* fingerlings up to 80% in order to foster growth, while at 40% pawpaw seed powder meal supplementation mortality was decreased.

## Safety concern of non-edible fruit seed

Seeds of apple, despite their therapeutic and nutritional potential, contains cyanogenic glycosides like amygdalin and prunasin, which can release toxic hydrocyanic acid (HCN) when damaged or processed, potentially causing health issues. However, there is no strong evidence to support the fact about the poisonous effects of apple seeds on human health, thus necessitating the research in this direction (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Current reports indicates that the average amygdalin content in seeds of fifteen different varieties of apples ranges from 1.0 mg/g to 4.0 mg/g (Bolarinwa, Orfila, and Morgan 2015). Apricot seeds contain amygdalin as the primary cyanogenic glycoside and gets degraded to cyanide on grinding and chewing (EFSA 2016). The estimated safe quantity of apricot seeds for adults is 0.37 g of seeds per day, while for toddler it is 0.06 g of seeds per day without exceeding the acute reference dose (ARfD) (EFSA 2016). On the other hand, it is unfeasible for consumers to measure such small quantities at home (EFSA 2016). Various toxicological studies have been validated the safe administration of jamun seeds (JS) extract in human and animal physiological systems, with no observable behavioral changes, body metabolism and electrolyte balance (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Moreover, according to the guidelines outlined by the Organization of Economic Co-operation and Development 423 (OECD), a study was conducted to assess the acute toxicity of JS extract in mice. The study results revealed that using JS extract at a dosage of 2000 mg/kg body weight (BW) for long-term administration was deemed safe, and no observed behavioral, fatalities and central nervous system changes were accorded (Kumar, Padmanabha, and Krishnan 2007). Sub-acute long-term studies showed no significant alteration in triglycerides, lipoprotein and cholesterol level at low dose of 1000 or 2000 mg/kg BW, supports the manifestation of an hypolipidemic effect even at high dosage of 3000 mg/kg BW. Nevertheless, the administration of higher doses did not result in any substantial changes in plasma glucose and electrolyte levels. The stability of enzyme activity of creatine kinase (CK) and lactate dehydrogenase (LDH) provides evidence for the cardiac safety of the intervention. Supplementation with JS extract in animal trails have been found to lower serum triglyceride, total cholesterol, LDL-c and VLDL-c levels, while increasing HDL-c levels. JS extracts are also known to have increased antioxidant enzyme (catalase, glutathione peroxidase and superoxide dismutase) activity and regulated the concentrations of thiobarbituric acid-reactive substances (TBARS) and TNF-α. In terms of hepatoprotective activity, increased concentrations of total proteins and albumin, preservation of the histological structure of liver tissue and decreased levels of bilirubin and liver enzymes (alanine aminotransferase, alkaline phosphatase and glutamic oxalocetic transaminase) (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Litchi seeds have been accorded to have varying concentration of hypoglycin A (HGA) and methylenecyclopropylglycine (MCPG), which is a decisive index to evaluate the safety for consumption as nutraceutical source (Kumar, Bhardwaj, et al. 2022; Kumar, Hasan, et al. 2022; Kumar, Zhang, et al. 2022; Kumar, Barbhai, et al. 2022). Previously published study has confirmed that both HGA and MCPG toxins are responsible for acute encephalopathy and gastrointestinal complications in few regions like India, Vietnam and Bangladesh (Shrivastava et al. 2017). Thus, use of litchi seeds as healthy ingredients demands optimization of its ratio in pharmaceutical or food formulation, which depends on the concentration of HGA and MCPG. Hence, the safety of extracts of litchi seeds are assessed for various bioactivities like anticancer, antioxidant, anti-obesity and neuroprotective in targeted cell lines as well as cytotoxic concentration on the normal cells. For example, 3-(4, 5-dimethyl-2-thiazolyl)-2,5-diphenyl-2Htetrazolium bromide assay at a concentration of 30 µg/mL, the extracts of litchi seed were determined to be safe for developing health promoting products (Saisavoey et al. 2018). Mango seeds are well-known as the rich source of tannins and are known to encompass cyanogenic glucosides, oxalates, and trypsin inhibitors that reduce the growth rate and nutrient utilization in poultry and pigs (Beyene and Araya 2015). Furthermore, autoclaving and boiling mitigate the anti-nutritional factors as tannins of trypsin inhibitors (Farag 2001). Papaya seed extract has been found to be associated with mild to severe hepatocyte metaplasia and liver cirrhosis in albino (Wistar) rats (Udoh and Udoh 2005). Ayotunde et al. (2010) determined the 1.29 mg/L concentration of papaya seed powder to be potentially harmful for catfish fingerlings.

## Limitations of the study

This study is subjected to inherent limitations as it follows a narrative review methodology, which lacks a systematic approach and hence it cannot be replicated. Nevertheless, narrative literature review articles play a critical role in the realm of continuing education as they facilitate the dissemination of up-to-date knowledge on a specific topic. These reviews undertake the task of analyzing and amalgamating pertinent research findings to present arguments that are based on the existing knowledge. It is important to acknowledge that this review does not cover all non-edible seeds like peaches and citrus fruits. The reason for exclusion of citrus seeds is supported by the facts of existence of numerous species like *Citrus aurantium* (sour orange), *C. bergamia* (Bergamot), *C. clementina* (clementine), *C. japonica* (Kumquat), *C. junos* (Yuzu), *C. limon* (lemon), *C. medica* (citron), *C. paradisi* (grapefruit), *C. reticulata* (mandarin, tangerine) and *C. sinensis* (sweet orange). Furthermore, this review does not explore the processing methodologies involved prior to the integration of non-edible seeds into animal feed and food application. Lastly, the review does not provide insights about the incorporation of mentioned non-edible seeds in the diets of both small and large ruminants.

## Conclusion and future perspectives

From this review, it can be concluded that fruit waste especially, the seeds can be potentially used as a functional food to enrich different food product and animal feeds. This approach of utilizing fruit waste i.e., seeds will not only play role in reducing environmental pollution but, can also have additional benefit on human health by providing strength to human to combat different ailments. In fact, fruits seeds are known to comprise of extensive bioactive molecules that can be utilized in food and pharmaceutical industries. Toxicity studies have consistently demonstrated a positive safety profile for non-edible seeds powder or extracts. Nevertheless, there is a imperative need for further research to investigate the potential use of these non-edible seeds in developing natural preservatives or functional food for both animal feed and food applications to improve or attain distinct nutritional attributes while maintaining the sensory palatability and adhering to established safety limits. The potential of fruit seed bioactive constituents and oil on humans with diabetes, cancer, compromised immunity and other disease have not been investigated in *in-vivo* condition, even though the data of few fruits seeds have shown promising results. Further, lipidomic approach could be used to find the bioactive substance(s) by examining the structure-activity relationship of bioactive molecules in relation with bioactive lipids. The exploration in this direction will allow researchers to attain the goals of United Nations Sustainable Development programme, that is, reduce waste, improve resource efficiency and standardize sustainability practices for exploring new agro-food based industrial by-products, which will undeniably raise the value of fruit seeds as functional food and also as a source of bioactive components of commercial interest with application in diverse industries.

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