Chapter 10
Kinnow Mandarin (*Citrus reticulate* L.)

Isha Dudeja, Arashdeep Singh, Ramandeep Kaur Mankoo, Avneet Kaur, and Sukhvinder Singh Purewal

10.1 Introduction

Kinnow is a citrus fruit that belongs to the "Mandarin" family and is widely grown in India and Pakistan. The fruit was first created in 1935 at the University of California Citrus Experiment Station and was first introduced in India in the early 1940s (Mahawar et al. 2020).

Kinnow is a cross between the citrus cultivars "King" (*Citrus nobilis*) and "Willow Leaf" mandarin (*Citrus deliciosa*) (Rattanpal et al. 2017). In India, the orange family, comprising mandarin and kinnow, produced around 4.75 million tonnes from an area of 0.43 million hectares (Mahawar et al. 2019). After its discovery, it was released for commercialization in 1935. However, the developed hybrid did not make a breakthrough in the United States, but when introduced in other citrus-producing countries like India, Pakistan and Bangladesh, a revolution in the citrus industry resulted owing to its stunning golden-orange colour, great yield and economic returns. Citrus cultivation is a successful enterprise that contributes

I. Dudeja · R. K. Mankoo
Department of Chemistry, Punjab Agricultural University, Ludhiana, Punjab, India

A. Singh (✉)
Department of Food Science and Technology, Punjab Agricultural University, Ludhiana, Punjab, India

A. Kaur
Department of Chemistry, Chandigarh University, Mohali, Punjab, India

S. Singh Purewal (✉)
University Centre for Research & Development (UCRD), Chandigarh University, Mohali, Punjab, India
e-mail: sukhvinder.e14148@cumail.in

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considerably to the economies of countries such as the United States, Mexico, Greece, China, Spain, India, and Iran, among others. India is fifth in the world in terms of citrus fruits production, with important fruits including oranges, limes, grapefruits, mandarins, lemons, and tangerines. Citrus fruits occupy 10% of the total production land among fruit crops in India, and their output ranks third behind mango and banana. Citrus fruits mainly Kinnow are mostly planted for juice extraction and processing. The citrus fruit processing business generates a lot of trash in the form of seeds, skins, and fruit peel and pomace.Citrus peels and seeds may include useful chemicals such as polyphenols, flavonoids, antioxidants, limonoids, carotenoids, and tocopherols. Citrus processing companies discard those Kinnow mandarin wastes, which contain a wealth of bioactive chemicals with antioxidant potential. Such organic matter has a significant potential for transformation into nutritionally valueable commodities using a variety of extraction processes. The extraction of bioactive phytochemicals from byproducts, which may then be isolated and used as nutritional supplements in food production systems.

10.2 Cultivation

Citrus being the third most consumed fruit covers 1.078 million ha and accounts for 12.5% of total fruit cultivation. Kinnow accounts for 4.6% of the citrus area and 3.6% of total fruit production. H.B. Frost was the first to develop Kinnow(*Citrus nobilis* × *Citrus deliciosa*) (Rattanpal et al. 2017) and for cultivating Kinnow specific temperature, soil and nutrient conditions are requisite. The temperature necessary for cultivation ranges in 10–35 °C. Kinnow can withstand temperatures as high as 40 °C in summer and as low as 0 °C in winter. An ideal site for Kinnow cultivation requires clay loam soils with a pH ranging between 6.0 and 7.5. It is usually propagated via budding onto specific rootstock around August–September and February–March. Irrigation is done using the drip method and the frequency depends on the climatic factors (Kumar et al. 2016).

10.3 Taxonomical Classification

Kinnow is taxonomically classified with the scientific name *Citrus nobilis* x *Citrus deliciosa*, having common name Kinnow mandarin, and belongs to the domain of Eukaryota, Kingdom of Plantae, Phylum of Spermatophyta, Subphylum of Angiospermae and Class of Dicotyledonae.

10.4 Physiological Traits of Kinnow

Kinnow fruit is oblate, flattened, and bright orange-yellow in color. The two main sections of the fruit are the pericarp (peel) and endocarp, while the pericarp branches into the epicarp (flavedo) and mesocarp (albedo). This mid-season cultivar has a few seeds adhering to 9–10 portions, a silky peel that becomes deep orange as it ripens, and tasty juice (Ladaniya 2008). When the total soluble solids (TSS)/acid ratio reaches 12:1–14:1 and the exterior color turns to orange, the fruit is considered fully mature (Table 10.1). The best time for Kinnow picking ranges from November to February (Anonymous 2018).

10.5 Harvesting, Postharvest Losses, Waxing, and Packaging

Kinnow is traditionally picked utilizing clippers, then dropped to the ground and gathered in boxes or bags, resulting in severe post-harvest loss. Fruit that has been damaged during harvesting is unsuitable for eating or marketing. Picking (19.6%), packaging (3.5%), carrying (2.2%), loading and transportation (7.1%) accounts for 32.4% of Kinnow post harvest wastage (Ahmad et al. 2015). Total harvest and post-harvest losses in Kinnow, according to Singh et al. (2016), range from 25% to 30%. Waxing is an important unit process that is commonly utilised in industrial catchment areas. As a result, Kinnow seems to have an extremely short shelf life of 8–10 days in moderate environments, that can be prolonged to 20 days with appropriate planning. Fruits are typically manually packaged in corrugated fiberboard (CFB) racks or boxes with a capacity of around 10 kg per box.

10.6 Varieties – Local, PAU Kinnow, Daisy, W. Murcott

Local The fruits of this variety mature in December and January. They have characteristic shapes and possess small furrowed necks at the base. It has excellent cadmium yellow color and contains 3–7 seed per fruit making it more convenient for

Table 10.1 Characteristic of Kinnow at maturity

Characteristic	Quality indices of Kinnow
Colour	Golden yellow (peel), deep yellowish orange (pulp)
TSS/acid ratio	12:1–14:1
Size	5.0–9.7 cm
Shape	Moderate to oblate; both base and apex flattened or slightly depressed
Appearance	Very smooth, glossy and sometime faintly pitted
Firmness	Firm, not soft and easily peel able

Fig. 10.1 Varieties of Kinnow (Source: Rattanpal et al. 2017)

out of hand eating. The acidity of juice is slightly high as compared to others. This is mainly cultivated in small regions in Hoshiarpur, Ropar and Gurdaspur districts of Punjab.

PAU Kinnow It is reported to be produced via mutation breeding. The fruits appear as globose to oblate in shape. The color is usually golden orange after attaining maturity. The Kinnow of this variety is said to have fewer seeds (0–9 to fruit) as compared to other varieties. The TSS and acidity value range between 10–11° Brix (B) and 0.7–0.9%.

Daisy It matures in first to third week of November. The skin of fruit appears to be glossy reddish golden. It has high sugar to acid ratio and possesses good flavour. The fruits are medium to large in size. The daisy consists of a moderate number of seeds (10–14/fruit).

W. Murcott The fruits are small to medium size with flat shape and easily peelable skin. The fruits are rich in flavour with perfect balance of sugars and acid. They contain less seed when self-pollinated as compared to cross pollinated. It is mid-season variety.

The different varieties of Kinnow are shown in Fig. 10.1.

10.7 Parts of Kinnow- Peel, Pulp and Pomace, Juice, Seed and Leaves

The peel, pomace, seed and juice of Kinnow is filled with wide range of nutrients having role in functional properties. The following description of each part of *Kinnow* clearly justifies their role:

Peel Fruit juice extraction is done on the same scale as fresh fruit consumption. The peels and pith are byproducts of juice extraction or fresh consumption. The Kinnow peel waste several bioactive chemicals (flavanones, polyphenolic compounds, and carotenoids) and essential oils that have applications in a variety of industries. Based to certain findings, the Kinnow peels, which account for 30–40%

of the total fruit, have more polyphenols and bioactive chemicals than the remainder of the fruit (Lim et al. 2007; Godara et al. 2020). As a result of the significant features of *Kinnow* peel, researchers have decided to investigate its potential as a fundamental element for various industries (Babbar et al. 2011; Rafiq et al. 2018). Albedo (inner layer) and flavedo (outer layer) are the two tissues that make up the *Kinnow* peel. Polyphenolic compounds present in the peels possess anti-inflammatory and anti-cancer effects (Tripoli et al. 2007; Xu et al. 2019). These bioactive components have a high nutritive value and are useful in industries such as pharmaceuticals, food processing, and biofuel production. The useful compounds can be extracted using various techniques. Albedo is primarily made up of different nutrients like sugars, proteins, minerals and fibre (Marin et al. 2007).

Furthermore, the flavedo generates essential oils that are used in the flavour and fragrance industries (Bejar et al. 2012). They are abundant in carotenoids, terpenes, and linalool (Mondello et al. 2005), and numerous studies have discovered antioxidant and antibacterial capabilities (Tepe et al. 2006; Jayprakasha et al. 2008; Viuda-Martos et al. 2008). Because the peel portion contains relatively more phenolics and has a higher potential for useful substances than the pulp has led researchers to investigate further. Approx 32–33% peel portion was observed in Kinnow. Kinnow peel comprises of 22.45% total solids, 12.50 °B TSS, 1.38% acidity, 41.57 mg/100 g vitamin C, 6.23% total sugars, 5.99% reducing sugars, 0.67% ash, 13.65 mg/100 g carotenoids, 7.43 mg/100 g β-carotene, 1.85% pectin, 0.420 mg/g naringin, 4.69 mg/g limonene and 0.77% fat content (Aggarwal and Sandhu 2003; Prem et al. 1994). The yield of ascorbic acid, pectin, naringin and limonin in Kinnow peel was reported to be 47.52 mg/100 g, 18.56%, 358μg/g and 60.75μg/g, respectively (Sidhu et al. 2016). Fresh Kinnow peel had 40.7 mg/100 g ascorbic acid and 374 g naringin, according to Maan et al. (2013). In Kinnow peel, Aggarwal and Michael (2016) observed 459 ppm limonin and 40.7 mg/100 g ascorbic acid. The total gallic acid, *p*-hydroxybenzoic acid, vanilic acid, *p*-Coumaric acid, Ferulic acid and the sum of other phenolic acid content in Kinnow peel was 252, 290, 664, 823, 1556 and 3585 μg/g, respectively.

Pulp and Pomace The pomace, or byproduct of processing Kinnow fruits to generate juices and various products, is utilized to produce pectin and syrup. The Kinnow pomace includes a variety of physiologically bioactive constituents such as antioxidant properties, polyphenolic compounds, and flavonoids, although their quantity is lesser than that found in the peels (Yaqoob et al. 2020). As a result, Kinnow pomace can be utilised as a primary component in the value addition of a variety of culinary items (Hayat et al. 2010). Natural antioxidants are becoming more popular as an alternative to artificial antioxidants in foods and pharmaceuticals. Considering chemical constituents have adverse health effects, the user's safety issue promotes the concept of natural antioxidants (Dilas et al. 2009). Consuming meals high in natural antioxidants helps to avoid illness induced by oxidative stress (Dilas et al. 2009). Oxidative damage is created by an unbalance among pro-oxidant and anti-oxidant molecules, that can be generated by an overabundance of pro-oxidant substances, a deficiency of antioxidants, or even both.

Kinnow pomace contains the most polyphenolic compounds in a confined state. The proportion of polyphenol content has indeed been found to be affected by geographical indication, cultivars, harvest time, warehousing, and processing parameters (Mallavadhani et al. 2006). After juice processing, the pomace has a significant concentration of glycosylated flavones, flavones, flavonoids, and polyphenols.The juice extraction residue (pomace) is abundant in glycosylated flavones, flavones, flavonoid, and polyphenols. According to Hayat et al., the Kinnow pomace possesses 18.4% and 30% in 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity and hydroxyl radical scavenging activities, correspondingly (2010). Research have been conducted to investigate the link between antioxidant properties and polyphenols in fruits and vegetables, and a linear association has been established (Minatel et al. 2017). The bulk of the polyphenol chemicals in Kinnow pulp are flavonoids and their derivatives such as flavones, flavonols, flavanones, flavonols, and anthocyanidins. According to the studies of Singh et al. (2016), the Kinnow pulp had 354.9 mg GAE/100 DW total phenolic contents and 261.3 mg QE/100 DW of total flavonoid content. In terms of DPPH and 2,2′-azino-bis (3-eth ylbenzothiazoline-6-sulfonic acid (ABTS), the antioxidant activity (mM trolox equivalent or TE/g) was found to be 2.9–3 and 3.3–3.5, respectively. Caffeic acid (16.8 mg/100 g), ferulic acid (12.3 mg/100 g), sinapic acid (14.4 mg/100 g), and kaempferol acid (14.2 mg/100 g) are among the polyphenolic found in Kinnow pulp.

Juice The Kinnow fruit is famous throughout India but is particularly well-known in Punjab and Rajasthan due to its unusual flavour and the presence of significant phytochemical components that are linked to a variety of health advantages. The Kinnow fruit juice content typically depends on a number of attributes, including cultivar, environment, cultural practices, etc. The juice is typically extracted by hand operating the machine on a smaller scale, which involves dividing the fruits in two and reaming the juice from the halves onto an appropriate rosette. Typically conical in shape, the rosette comprises ribbed or grooved sides. The oil cells in the peel are not damaged, and neither are the seeds, hence this method of juice extraction is the best. Contrarily, mechanical juice extractors are also available for the extraction of juice, in which the peel of the *Kinnow* may occasionally be manually removed before being placed into the screw-type juice extractor. Mechanical juice extraction method may produce a yield of about 60% whereas the manual method can produce about 40% of the juice. Due to changes in taste preferences, dietary customs, and consumer behaviour in recent years, there has been a surge in demand for processed Kinnow goods, primarily juice, as a result of increased Kinnow production in India (Bhardwaj and Pandey 2011). According to Bhardwaj and Mukherjee's (2011) studies, Kinnow juice was observed to possess 11.50°B TSS, 0.76% acidity, 21.15 mg/100 ml ascorbic acid content, 7.50% total sugars, 0.22 mg/ml limonin and 0.08 non-enzymatic browning. The total phenolic content, DPPH and ascorbic acid activity of Kinnow juice was reported to be 91.8 mg/100 ml, 59.19% and 52–53 mg/100 ml, respectively (Al Juhaimi et al. 2018). The physicochemical parameters of Kinnow juice are enlisted in Table 10.2. In developing the antioxidant potential of Kinnow juice, ascorbic acid also plays a crucial function in addition to phenolic components (Sun et al. 2002; Ghafoor, Al-Juhaimi and

Table 10.2 Physicochemical parameters of juice

Physiochemical parameters	Quantity/100 gm
Vitamin C	31.0 (mg/100 ml juice)
Ca	40.0 (mg/ 100 ml)
Fe	0.4 (mg/ 100 ml)
P	18.0 (mg/ 100 ml)
TSS	11.5 (%)
Acidity	0.9 (%)
TSS/acid ratio	12.0–14.0:1

Choi 2011). Kinnow juice is packed with vitamins such as ascorbic acid (31.66 mg/100 g), B1 (0.12 mg/100 g), B2 (0.01 mg/100 g), and niacin (0.43 mg/100 g). Natural Kinnow juice drink is much more nutritional, calorie-dense, and medicinal than manufactured drinks. Kinnow juice contains high levels of vitamin C, carotenoid, and polyphenols, as well as modest amounts of vitamin A, calcium, phosphorus, and iron, all of which assist considerably to the juice's total antioxidant potential (Peterson et al. 2006; Dhaka et al. 2016).Kinnow juice contains vitamin C, which serves as an antioxidant in the epidermis by intercepting and absorbing free radicals created by UV rays and reducing their oxidative stress (Okwu 2008). Because Kinnow juice cannot be marketed in their truest form due to quick bittering, attempts have been made to utilise Kinnow as a basic ingredient in the production of mixed juices as well as other products with additional value. Processing and storage are also required to reduce post - harvest loss owing to the highly perishable crop and the abundance of output throughout seasonal peaks (Mahawar et al. 2020).

Seeds Throughout the processing of Kinnow fruit for the production of various food items, a substantial quantity of waste in the form of Kinnow seed was discovered. Each Kinnow fruit has 20–25 seeds, and all these seeds can be utilised to produce limonin. These Kinnow seeds wreak havoc on the ecology and garbage handling (Matthaus and Ozcan 2012). Kinnow seeds are commonly accessible, and they possess biologically active compounds which can be employed as antioxidants. Several scholars studied the composition of Kinnow seeds in order to properly comprehend how to utilize them. Anwar et al. (2008) determined that the oil, protein, fibre, and ash content of Kinnow seed were 31.15%, 9.56%, 6.50%, and 5.60%, respectively. Babbar et al. (2011) determined that the antioxidant capacity of Kinnow seeds was 20.50 mg trolox equivalent or TE/g DW and total phenols were 3.68 mg GAE/g DW. Liu et al. (2012) employed an alkaline environment to extract limonin in their investigation, and the ideal pH is close approximately 11, the ideal temperature was 70 °C, the alkaline solution/seeds ratio was 20:1, and the ultrasonic power requirements used were 800 W for 30 min. The yield of limonin from citrus seeds obtained with 98% purity was 7.5 mg/g. According to Al Juhaimi et al. (2018), Kinnow seeds are a substantial source of essential oils such as palmitic, stearic, oleic, linoleic, arachidic, linolenic, behenic, and arachidonic in proportions of 15.77, 2.62, 23.53, 45.92, 0.36, 4.92, 0.29, and 0.10%. Essential oils are utilised in the culinary, pharmaceutical, and beauty sectors. Polyphenols, carotenoids, and

Table 10.3 Elemental composition of Kinnow seeds

Elements	mg/kg DW
Microelements	
Ca	7619
Mg	1186
K	10,334
P	3119
S	1132
Microelements	
B	12.91
Cr	0.396
Cu	9.30
Fe	40.50
Mn	6.08
M	0.318
Ni	0.51
Zn	14.67

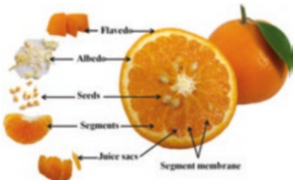
tocopherols are also abundant in these seeds.The main phenolic chemicals identified in Kinnow seed were kaempferol, isorhamnetin, catechin, and 1, 2-dihydroxybenzene (Al Juhaimin et al. 2018). Kinnow seeds'antioxidant activity and total phenolic content were reported to be 20.50 mg TE/g-DW and 3.68 mg GAE/g-DW, respectively. Furthermore, macroelements and microelements were observed to be present, as shown in Table 10.3. Furthermore, the estimated sugar content was 5.30, 5.83, 4.86, 5.59, 5.29, and 3.59 g/kg for glucose, fructose, raffinose, staxioz, saccharose, and galactose, respectively. In comparison to other fruit parts, the largest concentrations of limonoids, an important class of compounds, have also been detected (Yaqoob et al. 2020).

Leaves Owing of their possible central nervous network involvement, natural compounds can be employed as a reservoir of biomolecules to generate new analgesics that operate versus discomfort and include characteristics such as pungency, tingling, and needles. Although the leaves of *C. reticulata* Blanco (Rutaceae) are often swallowed to flavour the palate and produce this sort of impact on lips and tongues, the natural compound's composition may function as the foundation for various types of analgesics. Sharma and Tyagi (2019) tested numerous solutions extracted from different Kinnow preparations for phytochemical activity. The content of alkaloids, cardiac glycosides, flavonoids, steroids, saponins, and tannins was investigated in Kinnow leaf, peel, and pulp extracts.

10.8 Chemical Components – Pectin, Polyphenols and Flavonoids, Carotenoids, Essential Oil, Seed Oil

The chemical composition of Kinnow fruit is summarized in Table 10.4. Kinnow is rich in bioactives and fibres detailed information is presented below:

Table 10.4 Chemical composition

Part	Properties	Content	Reference
Whole fruit 	Weight	177.62 g	Mahawar et al. (2019)
	Volume	218.40 ml	
	Peel	29%	
	Pomace	25%	
	Juice	38%	
	No. of Seed	19.40	
	Firmness	5.86 kgf	
Peel	Thickness of peel	4.01 mm	Mahawar et al. (2019)
	Weight of flavedo	51.30 g	
	Weight of Pomace	44.20 g	
	Pectin	16.1%	Sharma et al. (2013)
	Total solids	22.5%	
	TSS	12.50°B	
	Acidity	1.38%	
	Ascorbic acid	41.57 mg/100gDW	
	Total sugars	6.23%	
	Reducing sugars	5.99%	
	Ash	0.67%	
	Carotenoids	13.65 mg/100 g DW	
	β- carotene	7.43 mg/100 g DW	
	Naringin	0.420 mg/g	
	Limonene	4.69 mg/g	
	Fat	0.77%	
	Total phenolic content	28.30 mg GAE/g DW	Saini et al. (2019)
	Total flavonoid content	4.40 mg QE/g DW	
	Antioxidant capacity	81.5%	Rafiq et al. (2021)
Pulp	Total phenolic content	345.9mgGAE/100gDW	Singh et al. (2016)
	Total flavonoid content	261.3mgQE/100gDW	
	Antioxidant capacity	50%	Mathur et al. (2011)
Seeds	Oil	31.15%	Anwar et al. (2008)
	Protein	9.56%	
	Fibre	6.50%	
	Ash	5.60%	
	Antioxidant capacity	20.50 mg TE/gDW	Babbaret al. (2011)
	Total phenolic content	3.68 mg GAE/gDW	
Juice	TSS	11.50°B	Mahawaret al. (2019)
	Acidity	0.90%	
	Turbidity	227.60 NTU	
	Vitamin C	23.50 mg/100 ml juice	

Pectin Pectin is a structural heteropolysaccharide that is typically derived from citrus fruit peels and is used primarily in the food industry as a gelling agent and stabilizer. It is made up of α-(1–4)-D-galacturonic acid units joined in a linear fashion. It finds its application as a biodegradable polymer in film formations, viscosity modifiers, coating agents, emulsifiers and chelating agents (Kanmani et al. 2014). Pectin appears as a white or brown powder with no odor. Pectin derived from the Kinnow peel has a wide variety of uses in the worldwide food business due to its usage in the creation of various food items such as jams, jellies, and preservatives. Pectin is typically removed chemically or enzymatically. Pectin separation is a multi-step procedure in which the material mixture is acidified with a powerful acid, the combination is maintained in a shaker, and pectin in the precipitate is produced when ethanol (96%) is added to the filtrate obtained in the shaker. Pectin was also recovered from Kinnow peel under various experimental circumstances such as temperature, time and pH using HNO3.

The yield of pectin obtained varied with these conditions and the highest yield observed was 16.1% in Kinnow peel at a temperature 60 °C, pH 1.75 and extraction time of 70 min. Pectin obtained from pomace (6.2%) was less at the same experimental conditions (Sharma et al. 2013). Ghoshal and Negi (2020) extracted pectin from Kinnow peel by ethanol precipitation method. The properties of pectin were assessed as a function of temperature, time and pH. pH was reported to be the determining factor for pectin yield and properties. The optimum pH observed was 5 and the yield obtained was 6.13%. In another study, Khule et al. (2012) reported the extraction of pectin peel and its utilization as a binding agent in paracetamol tablets. 18.21% pectin was extracted from Kinnow peel using ethanol treatment at pH 2 after 120 min of extraction. *In vivo* dissolution studies showed that 81.88% drug release was observed in pectin-bound paracetamol, indicating the potential use of Kinnow peel pectin as a binder. Pectin was isolated from pre-harvest fallen Kinnow by Bhatlu et al. (2016). The moisture, methoxyl content, ash content, equivalent weight, anhydrounic acid, and degree of esterification of the recovered pectin were all determined. The resultant pectin recovery yield of 57.5%, moisture 9.6%, methoxyl content 5.9%, degree of esterification 53.3%, and anhydrouronic acid concentration were 70%.

Polyphenols and Flavonoids Polyphenols are natural antioxidants by nature and are present in fruits, vegetables and some of their residues such as Kinnow peel. These are very beneficial for human health as it chelates with pro-oxidant ions present in the human body and acts as free radical scavengers (Wojdylo et al. 2007; Osman et al. 2009). Polyphenols are usually extracted by conventional methods such as solvent extraction method involving maceration with methanol, ethanol, etc. as solvents. However, as technology advances, many novel techniques of phenolic extraction, such as microwave-Assisted extraction (MAE), ultrasound-assisted extraction (UAE), supercritical fluid extraction, and accelerated solvent extraction, are being investigated for improved yield. Flavonoids, that are polyphenolic compounds, have a phenyl benzopyrone structure that consists of two benzene rings (C6) joined by a linear three-carbon chain (C3) with a carbonyl group at the C posi-

tion. While flavonoids are commonly considered non-nutritive agents, they have piqued the attention of many researchers due to their possible significance in the prevention of significant chronic illnesses. Citrus flavonoids comprise polymethoxylated flavones (PMFs) such as nobiletin and tangeretin, which are comparatively two common ones, as well as a family of glycosides known as hesperidin and naringin. Citrus fruit peels contain the greatest quantities of PMFs when compared to other palatable segments of the fruit. According to Liu et al. (2012), for the recovery of flavones from *C. reticulate* using accelerated solvents extraction, methanol appears to be the most efficient extraction solvent when compared to ethanol and water.

Sharma et al. (2016) studied the pattern of polyphenol constituents with antioxidants activity in Kinnow mandarin juicy sacs, both granular and non-granulated. Based on their observations, granulated Kinnow has a low concentration of polyphenol components (4.3 mg GAE/100 ml), ascorbic acid (16.2 mg/100 ml), and antioxidant activity (1.78 mol Trolox/g). Nongranulated Kinnow extracts, on the contrary hand, indicated significantly greater levels of polyphenol components (11.3 mg GAE/100 ml), ascorbic acid (28.6 mg/100 ml), and antioxidant activity (9.51 mol Trolox/g). MAE of polyphenols from Kinnow peels was performed in research (Hayat et al. 2009), and the results were matched to UAE and rotational extraction. The best extraction parameters were discovered to be 152 W microwave power, 49 s extraction duration, a liquid -to -solid ratio of 16, and a level of 66% methanol (solvent). Gallic acid, *p*-hydroxybenzoic acid, vanillic acid, *p*-coumaric acid, and ferulic acid were amongst the polyphenols acids recovered. These phenolics were examined for antioxidant efficacy and matched to various traditional procedures such as ultrasound and rotary extraction, with MAE being shown to be the most efficient approach due to its low time utilization and high efficiency. Polyphenols were extracted from Kinnow peel using maceration and UAE methods using different solvents and results showed that maceration was least competent than UAE procedure in extraction of polyphenols. In extracts prepared using maceration methanol (80%) extract had a higher content of polyphenols than ethanol, while ethyl acetate extract (80%) had the lowest polyphenol content. Safdar et al. (2017a, b) showed that when polyphenols were extracted from kinnow peel that 80% ethanol produced hesperidin and ferulic acid at concentrations of 92.9 and 65.2 g/g dry sample, respectively. Tumbas et al. (2010) identified hesperidin (80.9 mg/g extract) and narirutin (15.3 mg/g extract) in mandarin peel extract, which displayed high DPPH and hydroxyl free radical scavenging capabilities of 0.179 mg/ml and 0.415 mg/ml, respectively. The total polyphenolic content in Kinnow peel and pulp recorded was 148 and 76 μg/g GAE, respectively. The superoxide anion radical scavenging capability is maximum for ethanol extract of Kinnow peel (87%) and pulp (50%) among extracts prepared in water and chloroform (Mathur et al. 2011). Hayat et al. (2011) discovered phenolic components were found in concentrations ranging from 32.9 to 63.2 mg GAE/g in different kinnow cultivers among which ponkan variety showed maximum concentration while Kinnow had lesser phenolic and flavonoids compounds. The total flavonoid content observed in mandarin peel was 4.20 mg QE/g of extract powder. The mandarin peel

extract possessed 84.61% nitric oxide scavenging capacity at 200μg/mL and 73.9% at 800μg/mL DPPH scavenging capacity (Olyad et al. 2020). Safdar et al. (2017a, b) in their study revealed presence of eleven polyphenolic compounds from Kinnow peel extract and the most abundant were ferulic acid and hisperdin. Rafiq et al. (2021) in their study reported that total phenols and flavonoids present in the extract were 24.51 mg GAE/g and 9.12 mg QE/g, respectively while the freeze-dried peel extract has DPPH radical scavenging capacity of 81.5%. Microwave heating increased the yield of flavanone glycosides from Kinnow peels having 4975.4 g/g DW of naringin, 820.7 g/g DW of naringenin, and 53.0 g/g DW of hesperidin, whereas non-heated Kinnow peel powder was 3915.8 g/g DW of naringin, 655.3 g/g DW of naringenin, and 42.5 g/g DW of hesperidin (Hayat et al. 2010). Saini et al. (2019) estimated polyphenolic content, flavonoids content and antioxidant activity from citrus peels. The extraction was done using maceration and UAE; it was observed that the higher yield from Kinnow peel was obtained *via* UAE method (5.85%) rather than maceration (5.20%) furthermore the phenolic and flavonoid contents was maximum in UAE sample (28.30 mg GAE/DW and 4.40 mg CE/g DW, respectively) and lowest when extraction was done using maceration (23 mg GAE/g DW, 3.75 mg CE/g DW, respectively).

Naringin Naringin is a flavonoid found in Kinnow peel, especially in young fruits; it, together with other compounds such as limonene, is chiefly accountable for the bitterness of Kinnow peel. It is widely used in the pharmaceutical and food sectors. Naringin has antioxidant and anticancer characteristics, which make it useful in the pharmaceutical sector. It is said to lower levels of cholesterol, defend from carcinogenic compounds, and fight against poisons during chemo (Gorinstein et al. 2006; Jiang et al. 2006). Researchers employed solvent extraction (Bhatlu et al. 2017; Bhatlu et al. 2016), supercritical carbon dioxide extraction (Yu et al. 2007), precipitation technique (Tripodo et al. 2007), and adsorption techniques to retrieve naringin from peels (Jiang et al. 2006). Because the naringin concentration in immature fruits is higher, pre-harvest fallen fruits may be used in the recovery method, which is commercially favourable to producers. Researchers looked at removing bitterness from Kinnow peel and pomace by separating naringin and limonene (Singla et al. 2021). The acetone solventogenesis approach yielded the maximum yield of naringin and limonene from Kinnow peel and pomace. This technique employs a by-product and offers a long-term remedy (Singla et al. 2019). In Kinnow, pre-harvest dropping is an issue, and the fruit that drops off might be utilised to recover pectin and naringin (Bhatlu et al. 2016). The unripe Kinnow pulp was boiled, and the resultant liquid was passed across Indion PA 800, a native raisin, whereupon naringin is captured. After desorbing the immobilized naringin with ethanol, the mixture was screened and naringin was obtained by boiling the residue. The naringin retrieved was 52% pure, with an eventual purity of 91–93%. In a research on the chemical characterisation of naringin retrieved from Kinnow peel waste, Puri et al. (2011) discovered that rhamnose (an essential component for the food industry) can be generated from naringin using α-l-rhamnosidase. These stud-

ies demonstrate the usefulness of naringin in a variety of industries, as well as a method for using Kinnow pulp waste.

Carotenoids Kinnow mandarin accumulates carotenoid in a similar but more complicated pattern than orange fruit. Mandarin peel and pulp contain more than twenty different carotenoids and xanthophylls at maturity, which is higher than oranges. Clementine mandarin peel contains four times less total carotenoids than Satsuma peel. Mandarins, like orange fruits, accumulated carotenoids primarily in the peel (up to 94% of total carotenoids in Dancy mandarin), with β,β-xanthophylls being the main constituents (68–90% of total carotenoids). The violaxanthin concentration varied between cultivars and tissues, with the *cis*-isomer outnumbering the *trans*-isomer.

The chloroplastic carotenoids were the most prevalent in the green fruit peel, while the concentration of β,β-xanthophylls rose following the colour break in both the peel and the pulp. The increased accumulation of xanthophyll β-cryptoxanthin and apocarotenoids in mandarin fruits distinguishes it from oranges. β-Cryptoxanthin accumulates in the peel and pulp of mandarin fruit, contributing to their strong colouring. The C-30 β-apocarotenoids β-citraurin and β-citraurinene are especially plentiful in the peel, which gives mandarin fruits their unique orange-reddish colour. The relative proportions of red β-citraurin and orange β-cryptoxanthin are regarded to be the key contributors to the colour in Dancy mandarin, despite the fact that violaxanthin accounted for more than half of total carotenoids (Gross 1987). Another example of rich colouring is Michal mandarin juice, which appears to be due to high levels of β-cryptoxanthin and zeaxanthin in the pulp (Farin et al. 1983). It is worth noting that the differences in carotenoid composition between flavedo and pulp are more pronounced in mandarin fruits than in orange fruits. Carotenoids isolated from Kinnow peels utilising a cellulolytic enzyme and improved carotenoids stability (Nadeem et al. 2018). The combination of CMCase and pectinase (250 IU/100 g peel) produced the maximum carotenoid production (8.60 mg/100 g peel). Furthermore, the recovered carotenoid pigments were highly stable in the darkness at 30 °C compared to the open, and because resilience diminishes with rising temperature, freeze-drying the pigments culminated in better durability. The lutein was recovered utilizing the UAE technique with methanol as the extraction solvent, with the optimal parameters being 43.14 °C, 6.16 mL/g solvent/solid ratio, and 33.71 min time duration (Saini et al. 2021). These circumstances resulted in the highest lutein output (29.70 g/g).

Essential Oils Several research findings have advocated various ways for obtaining essential oils from Kinnow peel. Hydro distillation, centrifugation, hydrodistillation of fresh peel, hydrodistillation of manually dried peel powder, and hydrodistillation of sun dried peel powder are all methods of extracting oil from Kinnow peel. Javed et al. (2014) extracted essential oils from fresh Kinnow peel using the hydro-distillation method, yielding 0.33% and taking 210 min. Kamal et al. (2011) employed the hydro-distillation procedure to extract essential oils in a comparable manner. Their research revealed that the essential oil content ranged

from 0.30 to 0.50 g/100 g in fresh peels, 0.24–1.07 g/100 g in ambient peels and 0.20–0.40 g/100 g in oven-dried peels.

The mechanically dried peel powder obtained by hydro-distillation contains the highest oil concentration and comprises higher essential oils than fresher peel, most probably due to oil pore bursting through the powdering process. It also meant that a physical process such as centrifugation created a high redness value in a short period of time.

Terpenes were the compounds present in the oil of *C. reticulate* leaves that give kinnow and other leaves of citrus plants their pungent flavor and it was discovered to be a methyl-N- methyl anthranilate compounds as confirmed by 1D and 2D NMR spectroscopy, which is responsible for this bitterness. This chemical resembles another type of molecule with antinociceptive effects. These compounds with this action might be utilised to discover new analgesics for pain relief (Correa et al. 2016). The essential oil obtained from hydro-distillation of *C. reticulate* Blanco var. Kinnow (seedless and seeded) leaves revealed that oil contains 62.00% of β- phellandrene, 6.53% of β-pinene, 2.81% of β-myrcene and limonene both and 0.51% of caryophyllene as the prime components. In another study, its was reported that the essential oil obtained from low-seeded kinnow contains 37.35% β-phellandrene, 2.79% α-pinene, 3.26% β-pinene, 4.16% β-myrcene, 5.77% limonene and 1.41% caryophyllene as the main component when quantified by GC-MS. These were the five main components that accounted for about 100% of the total oil composition. Furthermore in their study, the researchers showed that microwave-assisted hydrodistillation (MAHD) had higher extraction efficiency of 6.8%, followed by microwave extraction (ME) having an extraction efficiency of 5.5% and hydrodistillation (HD) with the least extraction efficiency of 3.6%, when all the techniques were compared. While there were some quantitative differences, all three techniques appeared to yield essential oils with a composition that was qualitatively similar. Mandarin peel essential oil has five distinct components, the majority of which were monoterpene hydrocarbons. While computing the data by GC-MS their results revealed oil compositions had 0.54%, 0.375% of *α*-pinene,0.414%, 0.284% of β-pinene, 1.405%, 1.461% of β-myrcene, and 97.64%, 97.88% of limonene as the major four compounds when extraction was performed by for HD and ME, respectively. Whereas, when oil was extracted using a combination of techniques, the oil contains 0.518% of *α*-pinene, 0.317% of β-pinene,1.104% of β-myrcene, 97.94% of limonene, and 0.122% of sabinene as major five components found in mandarin peel essential oil. The findings revealed that the combination approach dealing with MAHD was a feasible alternative solution to HD for shortening the time since it seemed to generate essential oils with a greater yield and comparable chemical characteristics and value to those generated using conventional techniques. According to reports of Sultana et al. (2012) essential oil recovered from Indian mandarin by hydrodistillation method showed limonene as the prime component (87.45%).

Caryophyllene oxide, caryophylla-3 (Correa et al. 2016), 7(14)-dien-6-ol, *α*-pinene and 2,6-dimethyl-1,5,7-octatrien-3-ol are the major compounds of

essential oil obtained via hydrodistilled from Nigerian *C. reticulata* Blanco and *Citrus aurantifolia* Swingle leaves (Lawal et al. 2014), whereas the chemical composition of *C. aurantifolia* (Ikotun) essential oil comprises of limonene and geranial. While the primary ingredients detected in the C. *reticulata* oil sample from Ikotun were 38.1% of citronellal, 25.9% of (Z)-β-ocimene, 14.5% of linalool, and 12.2% of limonene (12.2%), while the oils from Ijanikin included 22.7% of pinocarvone, 20.0% of *trans*-pinocarveol acetate, and 12.8% of β -thujone. The essential oil from *C. reticulata* Blanco cv. Kinokuni peels by mechanical pressing method under optimized conditions yield 0.689% that closely resembles the predicted value with limonene as the prime constituent having 56.76% configuration. GC-MS was also used to identify 64 components, accounting for 96.34% of the total oil. These essential oil at a concentration of 7.5–60 mg/mL as minimum inhibitory concentration exhibits broad-spectrum antimicrobial effects against different microorganisms with a zone of inhibition values ranging from 9.24 to 16.35 mm. *C. reticulata* (Kinnow), *Citrus sinensis* (Mussammi), and *Citrus x sinensis (Red Blood Orange)*, yield 0.86, 1.70, and 1.07%, respectively of essential oils, when extracted using Hydro-distillation extraction method and furthermore the chemical composition of these extracted essential oils revealed that they comprise of 46.30–54.57% of limonene, 10.02–24.00% of geraniol, and 10.05–14.00% of citraniol as major components of essential oils from three different citrus cultivars peels as stated above along with great antimicrobial effect with higher zone of inhibition against tested bacterial strains (Qadir et al. 2018). The steam distillation process extracted 0.34% of the essential oil from the huge Kinnow fruits' green peel. GC identified 24 compounds among the different oil components, which were made up of 15.33% of 6-methyl-5-heptene-2-one, 13.8% of carvone, 10.04% of *cis*-carveol, and 4.55% of thujanol, while the other twenty identified chemicals, accounting for 35.84% of the total oil, were only found in trace levels. The percentage of limonene in the Kinnow orange green peel oil was relatively low (2.76%), compared to the bulk of citrus oils (35–85%) (Mahmud et al. 2005).

Seed Oil Kinnow seeds are recognised as a possible oil resource due to unique fatty acid profile and substantial tocopherol content (Juhaimi et al. 2016). Moreover, since it is high in protein, minerals, and fibre, it might be utilised to make high-value items in addition to culinary purposes. Among the fatty acids, pammitic, stearic, oleic, *cis*-vaccenic, linoleic, linolenic, arachidic, elcosenoic, and behenic acid comprise 98.6% of its total fatty acid content. The seed oil exhibited an iodine value of 104.80 g of I/100 g, 1.4650.927 mg/ml of density, saponification value of 186 mg of KOH/g of oil, an unsaponified matter of 0.48%, acid value of 1.30 mg KOH/g of oil, color red color value of 2.50 and yellow value of 20.00. The oil had excellent oxidative stability of 2.64 at 232 nm and 0.81 at 270 nm as measured by specific extinctions along with 3.15 of *p*-anisidine value and 2.40 mequiv/kg of oil of peroxide value.

10.9 Antimicrobial Effect

Mathur et al. (2011) investigated the antibacterial properties of different peel and pulp extracts of Kinnow, orange, and shaddock against *A. niger*, *C. albicans*, *S. aureus*, and *S. pyogens*. The most effective antibacterial agent against *S. pyogens* was determined to be an aqueous extract of Kinnow pulp (zone of inhibition, ZOI = 25 mm), which was superior to aqueous extracts of pulp from orange and shaddock. In comparison to chloroform extracts of orange and shaddock, extract from Kinnow pulp was shown to be the utmost effective antibacterial agent against *S. pyogens* (ZOI = 17 mm), whereas Kinnow peel chloroform extract had the highest antimicrobial bacterial activity against *S. pyogens* (ZOI = 18 mm). The minimum inhibitory concentration (MIC) and inhibitory effect of the various solvent extracts of the leaves, pulp, and peel of *Citrus nobilis* and *Citrus sinensis* were evaluated against bacteria and fungi species. The MIC was found to be 18 g mL^{-1} for *B. cereus*, 25 g mL^{-1} for *P. aeruginosa*, and 30 g mL^{-1} for *C. albicans* in the ethanolic extract of Kinnow peel. The MIC was found to be 18 g mL^{-1} for *S. epidermidis* and 40 g mL^{-1} for P. vulgaris, in ethanolic extract of leaves; 20 g mL^{-1} and 25 g mL^{-1} for *S. typhimurium* and *T. viride*, respectively, in ethanolic extract of pulp; and 25 g mL^{-1} for *E. coli*, respectively, in benzene extract of Kinnow (Sharma and Tyagi 2019).

10.10 Debittering

Kinnow peels and seeds contain the main bitterness-producing substances (Naringin and Limonin). Development of limonin is the cause of delayed bitterness. In acidic circumstances, an enzyme (limonoate-D-ring lactone hydrolase, found predominantly in seeds) catalyses the conversion of limonoate A-ring lactone, a non-bitter precursor, to bitter limonin, resulting in prolonged bitter taste of juice after 3–4 h of extracting. Fruit elements such as the peel and seeds include varying quantities of bitter chemicals. Premi et al. (1994) reported that the peel has highest level of narginin order with concentration of 0.422 mg/g, followed by juice having narginin concentration of 0.230 mg/g while seed exhibits the lowest levels of narginin having a concentration of 0.134 mg/g, while seeds showed highest levels of lignin with a concentration of 9.50 mg/g followed by peel with lignin concentration of 4.69 mg/g and lowest in with juice lignin concentration of juice 0.218 mg/g. Ilame and Singh (2018) identified the hollow fibre membrane with a molecular weight of 30 kDa as the best choice for increasing the storage period of ultra-filtered Kinnow juice beyond 60 days without any usage of extra regulators. This showed that by physically removing seeds and peel (albedo + flavedo) prior to juice extraction, bitter taste levels might be reduced owing to less tissue disturbance. Around the globe, genuine attempts have really been undertaken to reduce or eradicate the bitter taste that is now found in Kinnow juice. A variety of compounds, such as naringin

dihydrochalcone and neohesiperidin dihydrochalcone, have indeed been identified to hide bitterness of juice through their sweetening index. Debittering could be performed by absorbing bitter compounds on vinyl-dodecylbenzene resins. Upon running bitter taste juice of Kinnow through sheets of polymeric adsorbent resins, Singh et al. (2009) noticed enhanced sensory qualities during storage. Kaur (2017) investigated the enzymatic debittering and fragrance improvement of Kinnow juice using the enzymes limonin dehydrogenase, naringinase, and b-glucosidase. The results showed an increment in glucose levels by up to 4.38 lg/ml, acidity by 30.13%, and total sugar content by 42.97 lg/ml, whereas there is a significant drop in the bitterness components such as limonin by 87.34% and naringin by 58.41%. Singla et al. (2021) investigated the debittering of pulp residue from *C. reticulata* (Kinnow). Naringin, a substance that causes bitterness, was converted by an enzymatic process into naringenin, a substance that does not cause bitterness, to track the optimization of debittering.

The naringinase enzyme was found to be successful in reducing the bitterness of Kinnow pulp residue in which naringin content was decreased by 66.19% along with an increase in naringenin content a non-bitter compound by 52.38%, when enzymes were used at concentration of 1 U/mg, and incubated for4 h at 50 °C temperature range, at pH of 4.5. A Naringinase immobilisation test on various matrices such as alginate, k-carrageenan and polyacrylamide at varied concentration was done (Puri et al. 1996) to ensure its applicability in Kinnow juice debittering. The results showed that the optimal matrix was 2% sodium alginate. The expansion of pH optima gave desired versatility for debittering Kinnow juice of varied pH, and temperature gradients showed enhanced thermo-stability, which may be advantageous if debittering costs decreased. After immobilisation, 30 U of naringinase hydrolyzed 82% of the naringin in 3 h. Alginate enabled simple homeostasis with no impediments to naringin inflow or naringenin/prunin outflow, in addition to good physical durability, indicating the possibility of its industrial use. Debittering was decreased by 60% once kinetic models were introduced to Kinnow juice and optimised with pure naringin. The immobilisation of naringinase on glutaraldehyde-coated hen egg white (1 g HEW beads, 10 U of naringinase, 37C, pH 4.0, and 48 h) was accomplished by optimising a technique including 1% glutaraldehyde cross-linking. Immobilisation was 140% efficient under optimum circumstances (5 U = g HEW, pH 3.0, 60C, and 5 h), but soluble naringinase gave 91% efficiency for conventional naringin hydrolysis. It delivered a 68% efficient debittering when used to debitter Kinnow mandarin juice (Puri et al. 2001).

10.11 Applications

10.11.1 Food Applications

The valorization of Kinnow in food products such as jams, fruit bars, bakery products is well pronounced and it is summarized as below (Fig. 10.2):

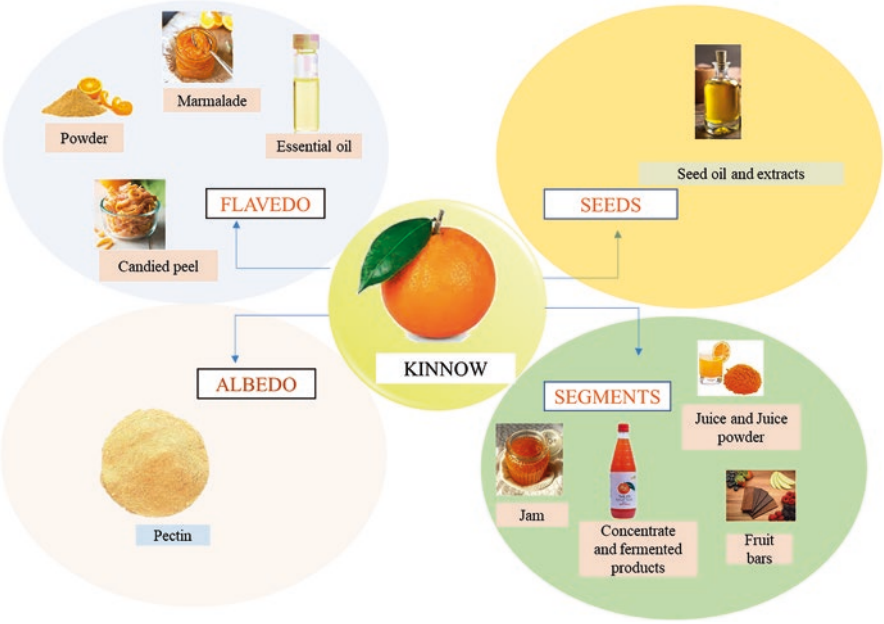


Fig. 10.2 Food applications of Kinnow

Bakery Products Kinnow residues (peel and pomace) and their phytochemicals were used to make functional cookies in place of wheat flour. The flour was replaced with dry peel and pomace powder at 5–20% levels, respectively, while phytochemicals were added at 1–4% levels. Cookies containing 10% peel, 5% pomace, and 4% phytochemicals received the highest sensory evaluations. The addition of Kinnow peel and pomace to cookies increased the crude fibre, ash, and L* value while lowering the spread ratio. Because of their strong DPPH and FRAP scavenging activity values, supplemented cookies performed better. Cookies containing peel phytochemicals had the greatest levels of phenolics 12.02 0.11 mg GAE/g, 0.47 0.06 mg QE/g flavonoids, and 0.76 0.03 mg/100 g carotenoids,. The produced cookies were more oxidatively stable than the cookies containing chemical antioxidants such as Butylated hydroxyanisole (Yaqoob et al. 2021). Similarly, Yaqoob et al. (2019) prepared muffins incorporating Kinnow peel and pomace by replacing wheat flour at concentrations *viz* 5, 10, 15, and 20%. In comparison to BHA substituted muffins (control), the supplemented muffins showed high levels of crude fibre i.e., 3.57% (peel) and 2.82% (pomace). Phytochemicals incorporating muffins were also prepared and at 4% phytochemical concentration higher phenolics content (12.34 mg/g of GAE), flavonoids (0.50 mg/g of QE), carotenoids (0.82 mg/100 g), and antioxidant activities i.e., DPPH (59.71%) and FRAP (23.46%).

Rafiq et al. (2022) studied the techno-functional, sensorial and nutritional characteristics of freeze-dried Kinnow peel powder incorporated soup sticks and it was observed that as the substitution level of the peel powder was increased in wheat

Table 10.5 Food applications

Part	Application	Reference
Peel and pomace	Cookies and muffins Improved crude fibre and ash Decreased spread ratio High DPPH scavenging and FRAP power High phenolic, flavonoid and carotenoid content Better oxidative stability	Yaqoob et al. (2019, 2021)
Peel (blanched and unbalanced)	Ice cream Better appearance, taste and overall acceptabilty. High contents of naringin, total soluble solids (TSS) and ascorbic acid	Mann et al. (2013)
Peel	Soup sticks Increased breaking strength, ash content, yellowness, visco-elasticity, baking and storage stability Decreased moisture content, crude protein, crude fat, pasting parameters, physical parameters, L* (lightness), and a* (redness) values.	Rafiq et al. (2022)
Peel	Candy Less bitterness development Appreciable content of bioactive components	Sidhu et al. (2016) and Sogi and Singh (2001)
Segments	Jam Less bitternes High overall acceptability	Sogi and Singh (2001)
Juice	Fruit bars High overall acceptability Good economic viability	Kaur (2017)

flour from 0 to 9% caused notable increase in properties such as breaking strength, ash content, yellowness, visco-elasticity, baking and storage stability. Furthermore, there was a significant decrease in moisture, protein, fat, pasting characteristics, physical properties, L* (lightness), and a* (redness) values. Furthermore, the digesting time for the prepared sticks was longer than that of the reference, and a study of the look and composition demonstrated a decrease in pore diameter. Raising the substitution amount boosted the strength of scent and colour but decreased taste, according to the sensory attributes. The application of Kinnow in food products is summarized in Table 10.5.

Candy According to Sidhu et al. (2016), osmotically dried Kinnow peel candy has ascorbic acid content of 30 mg/100 g, naringin content of 170 g/g, and limonin content of 38 g/g while peel powder had 40 mg/100 g of ascorbic acid 165 g/g of naringin, and 38 30 g/g of limonin content. According to Aggarwal and Michel (2016), sugar and fructose were utilised to turn the whole Kinnow with peel into candy. Kinnow candy has an ascorbic acid content of 11.2–11.4 mg/100 g and a limonin value of 410–412 ppm. Candied kinnow segments were placed in 30 B syrup and slowly cooked to 80 B in a study conducted by Sogi and Singh (2001). After being drained of the syrup, the sections were dry (at 55 °C for 5 h) and sprin-

kled with icing sugar. The stated quality criteria for the generated product were TSS (83.50 °B), acidity (0.65%), ascorbic acid (18.34 mg/100 ml of juice), total sugars (63.45%), reducing sugars (2.82%), and overall acceptability (7.73). There was no bitterness accumulation in candied portion during the storage time. Alam et al. (2019) utilised the osmotic drying process to make sweets from entire Kinnow fruit. The optimal configuration of more loss of moisture and lesser osmotic absorption was found to be the osmotic process temperature of 65 °C, sugar solution concentration of 65–75 °B, solution to fruit ratio of 5:1, and immersion duration of 270 min.

Beverages and Ice Cream Market-available blended juice are made from the concentrates of two or more different varieties. Kinnow juice is combined with citrus juice that is less acidic and bitter. The idea of blending juice has become popular recently, and there are numerous studies available in the same direction. A study conducted by Bhardawaj and Mukherjee (2011) showed the production of Kinnow: amnla: ginger (92:5:3) blended juice which possessed 12°B, 0.80% acidity, 45.30 mg/100 g ascorbic acid and 7.44% total sugars. The bacterial, yeast and mould population recorded was 7.69×10^3, 3.49×10^3 and 2.99×10^3 cfu/ml of juice, respectively. Mann et al. (2013) investigated the creation of ice cream using frozen Kinnow peel (unblanched and blanched) at concentrations of 1, 3, and 5%. Sensory and chemical evaluations revealed that ice creams with Kinnow peel supplements had a higher look, flavour, and overall acceptability. The levels of naringin, TSS, and ascorbic acid in made ice cream were high and increased as the amount of peel added increased. According to sensory assessment, the optimal concentrations of frozen Kinnow peel in ice cream were 3% for unblanched and 5% for blanched-5%.

Jam Sogi and Singh (2001) created jam from unpeeled and lye peeled Kinnow chunks and the prepared jams was concentrated to 70°B and stored at room temperature (16–20 °C) for 105 days in airtight glass jars. According to the sensory data, bitterness did not occur in jam created using lye-peeled segmentation until 105 days, although bitterness did show up in jam prepared from unpeeled segments after 30 days and increased with time. The jam has TSS of 70°B, acidity of 1.34%, ascorbic acid content of 26.33 mg/100 ml, total sugars content of 61.05% and sensory scores of 8.33 for flavour, 8.13 for colour, and 8.33 for overall acceptability.

Fruit Bars Kaur (2017) created a composite fruit bars with residual Kinnow, grape, and guava juice in various ratios, such as 100% Kinnow, 50% Kinnow and grapes, 50% Kinnow and guava, and 50% Kinnow and grapes. The juice waste was concentrated in an open pan technique at 80 °C till 40 °B using 20% sugar and 0.2% citric acid. The resultant mixture was spread in a thin layer (4–5 mm) on an aluminum tray and dried for 12–18 h at 50 °Cto a moisture content of 17–18%. Fruits bars prepared from Kinnow, grape, and guava were demonstrated to be good for storage for up to six months (14–32 °C). The average cost of the manufactured product was determined to be Rs 60/kg, confirming its economic feasibility from the perspective of both makers and consumers. The developed bar moisture content of 17.63%, total solids content of 82.37 °B, TSS of 69.97 °B, acidity of 1.30%, 64.95% of total sugars, 11.12% of crude fibre, 275.20 mg/100 g ascorbic acid, 920 mg/100 g of total phenolics, 4.60 mg/100 g of total anthocyanins.

Powdered Juice and Concentrates Due to its many benefits in terms of ease of handling, transportation, and storage, the production of fruit juice powder has grown significantly in recent years. A useful auxiliary for the ice cream, bread, and confectionery sectors is juice powder. The most popular technique for drying liquid foodstuffs is spray drying. Juyal et al. (2015) investigated the spray drying technique's capacity to create Kinnow juice powders and found recovery factor of 36.45% at a 60:40 (Kinnow juice: maltodextrin) ratio at 146.5 °C inlet temperature, and 26 °C feed temperature. The powder recoveries were 37.66% in a 40:10:50 mixture of maltodextrin, sucrose, and juice. The final optimized powder has 4.60–5.74% moisture, 86.07–87.24% of dispersibility, L* value of 85.01–85.89, a* value of 1.61–2.06, b* value of 12.48–13.88, colour change value of 52.31–53.18.

Concentrating liquid foods lower the costs associated with handling, storage, and transportation activities. The procedure also makes sure that fruit juice is used and accessible all year long. The concentration of Kinnow juice was carried out in a rotary vacuum evaporator at temperature of 50–60 °C under vacuum pressure of 27–28 inch Hg. The 72 °B juice concentrate was packed in a glass container with 700 ppm SO2 and kept at −18 °C without experiencing any noticeable changes in its physicochemical properties, nor did it exhibit any signs of fermentation or an off-smelling odour (Thakur et al. 2000). Khamrui and Pal (2002) used reverse osmosis to concentrate Kinnow juice while optimising temperature (40 °C) and operation pressure (40 bar). The resultant concentrated Kinnow juice has TSS of 23 °B, pH of 3.20, acidity of 2.49%, total carbohydrates content of 17.25%, reducing sugars content of 5.85%, sucrose content of 6.79%, viscosity of 6.21 cP, and sugar-to-acid ratio 9.23. The following percentages of acid components, total soluble solids, total carbohydrates, reducing sugars, and sucrose were recovered during the concentration process: 89.68%, 96.02%, 95.50%, 94.32%, and 98.22%, respectively. Reverse osmosis (RO) and vacuum thermal evaporation were used to concentrate Kinnow juice (Thakur et al. 2004). They also examined the effects of centrifugation (CF) and ultrafiltration (UF) (VTE). They indicated that juice may be clarified with UF and condensed with RO up to 26°B before being clarified with CF. Juice could also be clarified with UF up to 24–26°B. The corresponding quality parameters for VTE treatment were 43°B of TSS, 2.33% acidity, 56.48 mg/100 ml of ascorbic acid content, 19.0% reducing sugar, of total sugar and 1.79 mg/100 ml of carotenoid content. The statistical difference in the sensory properties of juice concentrate obtained using various methods was insignificant.

10.11.2 Green Catalyst

The powdered kinnow peel is said to be a cost-effective, environmentally benign, and long-lasting catalyst for the synthesis of Schiff base. N-Benzalideneaniline and its descendants were synthesised from benzaldehyde and aniline variants using powder of Kinnow peel acting as a catalyst. In tidy circumstances, the reaction yield was 78–85%(Verma et al. 2022).

10.11.3 Bioethanol Production

Ethanol was produced from Kinnow garbage and banana peels in 4:6 ratio at 30 °C temperature, with 6% of inoculum using concomitant saccharification and fermentation with cellulase and co-culture of Saccharomyces cerevisiae G and Pachysolentannophilus MTCC 1077 for incubation time of 48 h, and agitation for the first 24 h were shown to be optimum for ethanol production employing two byproducts. Following enzymatic saccharification, the pretreated steam exploded biomass containing 63 gL^{-1} reducing sugars were fermented under optimised reaction situations both with hexose and pentose fermenting yeast strains, yielding 26.84 gL^{-1} of ethanol, a yield of 0.426 g/g, and fermentation efficiency 83.52%, respectively (Sharma et al. 2007).

In a step of producing ethanol from Kinnow peel via simultaneous saccharification of crude filtrate extract produced by *Aspergillus oryzae* and fermentation with *Pichia kudriavzevii* revealed that pre-hydrolysis of Kinnow peel with crude filtrate extract at three cellulase filter paper units/g dry substrate (FPU/g-ds) at 50 °C resulted in glucose (24.870.75 g/l), fructose (21.980.53 g/l), sucrose (10.860.34 g/l), and galacturonic acid (6.560.29 g/l) and galacturonic acid (6.560. After 12 h, ethanol production declined, culminating in ethanol levels of 33.87 g l-1 and efficiency of 2.82 g l-1 h-1, respectively.

10.11.4 Other Applications – Cellulase Production, Reducing and Capping Agent, Nanocellulase Production, Animal Feed

Cellulase Production An research was conducted to see whether *Trichoderma reesei* Rut C-30 could manufacture cellulases from Kinnow pulp. Amongst some of the different permutations assessed, dehydrated Kinnow pulp blended with wheat bran in a 4:1 ratio generated the highest filter paper cellulase (FPase) activity of 13.4 IU/gds, but the better endo-1, 4-glucanase (CMCase) activity was revealed once Kinnow pulp was accompanied with wheat bran in a 3:2 proportion utilising Mandel Weber (MW) mode. The 3:2 ratio of Kinnow pulp to wheat bran in MW media resulted in the maximum amounts of β-glucosidase activity (18 IU/gds). In the case of pretreatment lignocellulosic substrate, an FPase:-glucosidase ratio of roughly 1:1 was deemed to be the most optimal for reaching the ideal saccharification effectiveness, which was achieved when water was employed as a vehicle with wheat bran to Kinnow pulp ratio of 3:2. The findings of this study explored the feasibility of employing Kinnow pulp for cellulase production and demonstrated that a substrate with little economic relevance and that causes environmental contamination due to inappropriate management may be utilised to make cellulases (Oberoi et al. 2011).

Reducing and Capping Agent for Nanoparticle Production Naz et al. (2017) demonstrated an effective approach for manufacturing nanoparticles (AgNPs) using Kinnow peel extracts as a reducing and capping agent in their study. AgNPs were synthesised utilising dilute and concentrated peel extract. For nano-particles (NPs) produced from diluted and concentrated extracts, ultra-violet-visible spectroscopic technique revealed different absorption maxima at 425 and 400 nm, respectively. The X-ray diffraction investigation of nano-fabricated silver revealed a pure face-centered cubic crystal structure with dimensions determined using the Scherrer formula of 27.4 and 18.1 nm. The synthesised NPs had a constant spherical form, according to SEM analysis. Antioxidant, bioactive components, and antimicrobial investigations indicate that the these AgNPs could be employed well in biological purposes. The AgNPs that were created have excellent anti - oxidative, phytochemical, and antibacterial activities. An ecologically benign approach was used to generate silver nano-particles by using Kinnow mandarian aqueous peel extract as the reducing and capping agents (AgNPs). A simple process was utilised to manufacture persistent silver nano-particles at ambient temperature using organic wastes from fruit peel. The shampoo containing synthesised AgNPs was developed, and its physical characteristics such as foaming ability, surface tension, pH, solid content, dirt dispersion test, and anti-microbial action against *Escherichia coli* and *Candida albicans*, two harmful microorganisms, were evaluated (Bala et al. 2017).

Nanocellulose Production Cellulose was extracted by immersing Kinnow peels in toluene: ethanol (2:1) solvent system followed by bleaching with H_2O_2 and alkaline treatment with 6% NaOH. The cellulose was converted into nanocellulose by acid hydrolysis with a mixture of HCl and H_2SO_4 and thee formed nanocellulose was characterized using XRD and SEM. The crystalline behaviour of nanocellulose obtained from Kinnow peel extract was evaluated using X-ray diffraction method and it was revealed that a single diffraction peak at 2Θ value of 22.34° confirmed the crystallinity of nanocellulose. The SEM micrographs revealed the dense arrangement of cellulose in the form of nanorods and needle-like structures depending upon acid mixture concentrations.

Animal Feed Kour et al. (2016) investigated the effect of Kinnow mandarin waste (KMW) added in the diet on feed consumption and nutrient absorption in goats. It was revealed that 40% Kinnow trash incorporation expanded the Ca: P ratio because of its high calcium content, demonstrating that preserving the ratio required careful thought when administering. Kinnow waste incorporation in the diet showed no detrimental impacts on the goats' general health, according to blood biochemical indicators.

10.12 Development of Natural Coatings for Kinnow

Edible coatings are less harmful to the ecosystem and people's health than petrochemical waxes. Baswal et al. (2020), performed research to examine the influence of different edible coatings on the fruit freshness and cold rooms lifetime of

'Kinnow'mandarin. On Kinnow fruit, uncoated (control) fruits were contrasted to treatment options with 1–2.0 g/L carboxymethylcellulose (CMC), 0.5–1.5 g/L chitosan, and 5–15 g/L beeswax. Both coated and untreated fruit were kept in refrigerated stores for a maximum of 75 days (5–7 °C and 90–95% RH). Fruit samples were collected following 30, 45, 60, and 75 days of cold storage and evaluated for several quality attributes on the peel surface employing SEM. The results demonstrate variance among the polymer coatings in terms of fruit's physical quality parameters, compositions, bioactive compounds and sensory attributes characteristics. All coating techniques increased fruit's shine, however, when the cold storing duration was prolonged, the chitosan and carnauba wax fruit exhibited rind breaches. In refrigerated temperature, the CMC (2.0 g L^{-1}) coating excelled overall in terms of maintaining fruit quality metrics such as SSC total soluble solids, acidity, ascorbic acid, and olfactory qualities, in addition to postponing the activity of cell wall-degrading enzymes such as pectin methylesterase and cellulase. The impacts of CMC and guar gum-based coatings incorporating silver nano-particles on the post-harvest preservation sustainability of Kinnow mandarin was studied for 120 days (85–90% relative humidity) at 4 °C and 10 °C (Shah et al. 2015). Physiological and microbial characteristics were assessed every 15 days during storage. Total solids, sugars, and loss of weight all rose generally, but in coated fruits held at 4 °C, the rise was less evident. Wrapped fruits with 4 °C storage exhibited considerably greater amounts of vitamin C, phenolic content, and antioxidant properties. In contrast to coated Kinnow stored at 4 °C, titrable acidity reduced dramatically. Positive control held at 10 °C showed significant levels of fruit withering but no chilling harm. Aerobic plate thermophilic microbes, fungi, and molds were discovered in all storage settings, although proliferation was low in coated fruits at 4 °C. Kinnow fruit may be maintained in excellent condition over 4 months at 4 °C and 2 months at 10 °C after coating. A research looked at the use of cellulose coatings with Calcium and Magnesium ions for Kinnow. The results revealed that by utilising 5% cellulose covering and 1% Ca and Mg salts, optimum conservation was accomplished, and Kinnow's quality and durability were superior to the control. The films deposited samples had the lowest physiology loss of weight, juice %, and chilling damage, as well as higher vitamin C, acidity, and lower total solids. In addition, fruit firmness was also maintained inhibiting ethylene production (Randhawa et al. 2018).

10.13 Conclusion

Kinnow production grows year after year, and it is distributed around the world due to its nutritious benefits. Because the fruit is high in bioactive components, it may be used in a variety of ways to maximise its value. New extraction procedures are being investigated in order to increase the yield and productivity of bioactive components that may be used in food items. However, debittering research is still in its early stages, and researchers are looking for new ways to remove bitterness. The current research trends using Kinnow or its byproducts are mostly focused on the extraction of fibres and bioactives found in it and their use in diverse industries.

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