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Original research paper

VALORIZATION OF KINNOW FRUIT WASTES - SUSTAINABLE APPROACH TOWARDS ENVIRONMENT

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Abstract: During the processing of kinnow into juice, around 30-34% of the fruit peel and an average of 20–25 seeds are generated as trash. Consequently, the present study aims to determine the elemental composition, proximate, and oil content of locally cultivated kinnow seed and peel. Kinnow peel essential oil was extracted by hydrodistillation, whereas seed oil was cold-pressed. Characterisation of both extracted oils was performed by FT-IR and GC-MS. The proximate analysis of kinnow seeds powder revealed that it contained proteins, fat, fibres, ash, moisture and carbohydrates in amounts of 13.00±0.32%, 28.65±1.06%, 6±1.28%, 4.771±0.90%, 14.63%, and 31.96 ± 1.10, respectively. The smoke point of kinnow seed oil was 148 °C, and pH, acid value, peroxide value, iodine value, refractive index, saponification value, and unsaponification matter were: 6.26 ± 0.01, 1.125 ± 0.02, 5.91 ± 0.64, 92.56 ± 1.08,1.46 ± 0.002, 187.2 ± 1.73, and 0.51 ± 0.17, respectively. Moisture content, crude fat, and ash of fresh kinnow peel were found to be 75.08%, 1.27%, and 2.77%, respectively. The water retention capacity (WRC), oil retention capacity (ORC), swelling index, and solubility of dried peel were 6.96g w/g DM, 3.22g oil/g DM, 22.90 ml water/g DM and 36.05% respectively. GC-MS revealed hexadecenoic acid was the most common saturated fatty acid in kinnow seed oil, with an area of 24.28% and retention time 35.9 min, followed by esconic acid with 1.12% area, 42.1 min retention time and stearic acid with an area of 6.59%, retention time 38.8 min. The most abundant compound in peel essential oil was D-Limonene, with a retention time of 7.42 min as identified by GC-MS.

Key words: *Citrus reticulata Blanco, peel essential oil, seed oil, GC-MS, FT-IR analysis*

INTRODUCTION

Kinnow (*Citrus reticulata Blanco*), a hybrid of *C. nobilis* 'King' and *C. deliciosa* 'Willow Leaf', belongs to the family Rutaceae and order Sapindales. Introduced for commercial cultivation in 1935, it was brought to India in 1954 by Dr. J. C. Bakshi at the Punjab Agricultural University Regional Research Station, Abohar (Usman & Fatima, 2018). Since then, kinnow has become the predominant citrus cultivar in northern India, particularly in Punjab, which accounts for approximately 29% of the country's total production—yielding around 1.1 million metric tonnes annually across 0.048 million hectares (Safdar et al.,

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2017; Mahawar et al., 2020). India is currently the third-largest citrus producer globally.

Kinnow processing generates significant agro-industrial waste, with juice industries discarding nearly 50% of the total fruit mass as by-products, amounting to more than 40 million metric tonnes (Sharma, 2017). These wastes, including peel, seeds, and pomace, are rich in bioactive compounds with antioxidant, antimicrobial, and potential therapeutic properties (Hayat et al., 2010). Despite their nutritional and functional potential, these residues remain underutilised.

Kinnow seeds, comprising 26–42% oil, are a promising source of edible oils rich in essential fatty acids, phospholipids, tocopherols, carotenoids, and flavonoids such as naringin, hesperidin, and rutin—compounds known for their pharmacological activities (Adeyeye & Adesina, 2015). Citrus seed oil, traditionally used in medicine, cosmetics, and industrial applications, has also demonstrated a favourable fatty acid profile and oxidative stability comparable to that of soybean and cottonseed oils (Swisher, 1977; Shahidi & Zhong, 2005). Given the global demand for plant-based oils, kinnow seed oil presents a viable alternative for food and non-food applications (Purewal, Kaur & Sandhu, 2022).

Kinnow peel, constituting 30–34% of total fruit weight, also holds significant value. The flavedo (outer layer) is rich in essential oils such as limonin, linalool, and terpenes, while the albedo (inner layer) contains pectin, minerals, and dietary fibre (Bejar, Mihoubi, & Kechaou, 2012; Rafiq et al., 2018). Extracts from kinnow peel are known to possess antioxidant, antimicrobial, and anti-inflammatory properties (Babbar, Oberoi, Uppal & Patil, 2011; Sidhu, Arora & Alam, 2016; Kamal, Anwar, Hussain, Sarri & Ashraf, 2011). Safdar et al. (2017) identified eleven phenolic compounds from kinnow peel, including chlorogenic, gallic, and ferulic acids, as well as flavonoids such as catechin, quercetin, and hesperidin.

In response to rising production, the National Horticulture Board of India has identified citrus-growing zones in Haryana (including Bhiwani, Sirsa, Fatehabad, and Hisar) to support cultivation through financial and technical inputs. This increase in production suggests a future rise in juice-processing infrastructure, with associated opportunities for utilising processing residues. Consequently, the present study investigates the extraction and characterisation of oil from kinnow (*Citrus reticulate*) peel and seeds, aiming to support sustainable waste management and enhance value addition in the citrus industry.

MATERIALS AND METHODS

Chemicals used in the study were procured from commercial sources and used as such.

Kinnow seeds and peels collection

Fresh kinnow fruit waste was procured from local juice vendors in Hisar, Haryana, India. The collected material was initially rinsed with tap water to eliminate crushed pomace, extraneous matter, chaff, and immature or damaged seeds using a fine-mesh sieve. Visibly deteriorated or unhealthy portions of the peel were manually removed. Subsequently, the remainning samples were thoroughly washed under running tap water to remove any adhering particulate matter, dust, and surface microbial contaminants.

Drying of collected seeds and peels

Kinnow seeds were dried in a hot air oven at a temperature of 35–40 °C. The dried seeds were then ground into a fine powder using a mechanical grinder and stored in airtight containers to prevent moisture absorption. Similarly, the collected kinnow peel was dried in a hot air oven (Model MSW-211, MAC, India) at a temperature range of 30–40 °C, depending on the quantity of material loaded. Once the peel reached a moisture content of approximately 5%, it was ground into a fine powder using a professional grinder (Sujata). The resulting peel powder was packed in low-density polyethylene (LDPE) bags and stored at 4 ± 0.2 °C to maintain its stability.

Proximate and physicochemical analysis of kinnow seed

Proximate analysis of fresh kinnow seed and peel was conducted following the standard procedures outlined by the Association of Official Analytical Chemists (AOAC, 1990).

Size and shape

The dimensions of the outer surface and iregular shape of the kinnow seed samples were determined by using a digital vernier calliper (CD-15 CP, Mitutoyo, Japan). The length, width, and thickness of 10 randomly selected

seeds were measured. The geometric mean diameter of size and shape in mm was calculated from the average of axial dimensions as explained in Choi, Kim and Moon (2021).

Estimation of the weight of a thousand seeds

The 1000-seed weight was calculated by weighing 100 randomly selected seeds and multiplying the obtained value by 10, as described by Wiesnerová and Wiesner (2004).

Determination of carbohydrate content

The carbohydrate percentage of the kinnow seed sample was estimated using the arithmetic difference method (Akpata & Akubor, 1999).

Extraction of kinnow seed oils by the mechanical expression process

Oil was extracted from 100 g of kinnow seeds using a mechanical press (Eco Smart, S-03, Eco Instruments, India). The temperature was set to 250 °C before extraction. Once the desired temperature was reached, the machine was activated, and the seed sample was fed into the oil press. The extracted crude oil was collected and stored at room temperature for subsequent analysis.

Physicochemical properties of kinnow seed oils

Determination of colour

The colour analysis of kinnow seed oil was done using chromameter (CR-400/410 (Konica Minolta, Japan)) was used for colour analysis. The measurements were recorded in CIE L*a*b* colour coordinates: L* (0 black, 100 white), a* (+ red, - green), and b* (+ yellow, - blue).

Estimation of acid value

In the present study, the acid value of kinnow seed oil was determined by titrating a 10 g sample of the extracted oil in an alcoholic medium using phenolphthalein as an indicator. The titration was carried out against a standard 0.1 N potassium hydroxide (KOH) solution until a permanent pink colouration was observed, indicating the endpoint (Yiming, 2003).

pH measurement

The pH of kinnow seed oil was estimated using a digital pH meter with an Electrode Type 335 controller-based pH system (Systronics, India).

Refractive index of oil determination

Using an Abbe 5 instrument (Labline Stock Centre, India), the refractive index of kinnow seed oil was determined (Baydar, Özkan, &Çetin, 2007).

Determination of saponification value

The saponification value of kinnow seed oil was calculated by the AOCS (1993) method. 2 g of kinnow seed oil were weighed into a 250 mL conical flask, and 25 mL of a 0.5 N solution of potassium hydroxide in ethanol was added. After attaching a reflux condenser, the flask's content was heated on a boiling water bath for one hour with intermittent shaking. While the solution was still hot, three drops of the phenolphthalein indicator were added, and it was titrated with 0.5 N HCL.

Determination of unsaponification matter

Unsaponification matter of kinnow seed oil was analysed according to the standard AOAC method (AOAC, 2000).

Determination of the peroxide value

The standard method (AOCS, 1997) was used to determine the peroxide value of the kinnow seed oil samples.

Determination of the smoke point

10 mL seed oil was taken and poured into an evaporating dish, and a digital thermometer was placed in the centre of the dish, ensuring the bulb was inside the oil without touching the dish. The temperature at which the kinnow seed oil sample continuously gave a thin, bluish smoke was noted as the smoke point.

Determination of the flash point of kinnow seed oil

The estimation of the flash point of kinnow seed oil by the AOAC (1990) 15th ed., Method 920.111.

Melting point of kinnow seed oil

At first, the oil sample was filtered through Whatman filter paper no. 1 to remove the impurities from the sample. Then the sample was placed in a test tube and placed in the refrigerator at 0 °C to -4 °C with a thermometer for 16 hours or overnight, so that the oil solidified. The oil sample was removed

from the refrigerator and placed on a heater. When the solidified oil starts to melt, the reading of the thermometer is noted as the melting point of kinnow seed oil (El-Adawy & Taha, 2001).

Freezing point of kinnow seed oil

Two sample containers (transparent glass bottles) were filled with kinnow seed oil and put in a freezer, and were checked every 30 minutes to see if the oil was frozen or not. The temperature of the freezer remained constant (Ouilly et al., 2017).

Physicochemical analysis of kinnow peel

Water and oil retention capacity

Water retention capacity (WRC) and oil retention capacity (ORC) measurements were performed for fresh and dried citrus peel samples. Water retention capacity (WRC) was measured after centrifugation of the water-insoluble residues. Samples (0.5 g each) were hydrated in excess (24 h) in a 50 ml tube, prior to centrifugation at 2000×g for 25 min. Excess supernatant was decanted. Water retention was recorded as g water/g dry sample. For measuring oil retention capacity (ORC), samples (0.5 g) were mixed with sunflower oil (10 ml), centrifuged at 2000×g for 20 min, and the excess supernatant was decanted. Oil retention capacity (ORC) was expressed as g oil/g dry sample **(**Garau, Simal, Rossello & Femenia, 2007).

Swelling index

The swelling index (SI) of dried citrus peel was determined using a settled bed volume method to measure swelling after equilibration in an excess of solvent. Dehydrated samples (0.5 g) were hydrated in 20 ml of distilled water. After equilibration (16 h), the volume of the sample was recorded and expressed as ml water/g dry (Femenia, Lefebvre, Thebaudin, Robertson & Bourgeois, 1997).

Solubility

Solubility was measured in conjunction with WRC, as % loss in the original sample dry weight after recovery of insoluble material used to determine WRC (Anwar et al., 2008).

Hydro distillation (HD) extraction of kinnow peel

Clevenger apparatuses were used for conventional hydro distillation as described by Shaw et al. (2023). In a 1000-ml flask, 100 g of dried mandarin peel powder was dissolved in 800 ml of distilled water. The flask was placed on the heating element first, followed by the Clevenger apparatus attachments and water supply lines. The vapour produced by heating the flask was condensed through the circulation of water in the condenser.

When the oil has been withdrawn, open the knob and collect the condensed material in the Eppendorf tube. The weight of the essential oil was determined, and the percentage yield of oil was estimated.

Characterisation of extracted seed oil and peel essential oil by FT-IR and GC-MS

The seed oil and essential oil of peel were analysed with a PerkinElmer Fourier Transmission Infrared (FTIR) spectrophotometer (Spectrum Two, PerkinElmer, USA) as described by Oliveira et al. (2016).

The standards and samples were analysed according to O'Fallon, Busboom, Nelson and Gaskins (2007), using a Thermo Fisher Scientific GC-MS, GC-Trace 1300 (USA) MS-TQS Duo, Autosampler: TriPlus RSH, Length: 40 m, ID: 0.15, Film Thickness: 0.15.

GC Conditions: 50 ºC (hold 5 min) to 210 ºC (hold 15 min) and with a ramp rate of 5 ºC/min.

MS Conditions: Fore line pressure temperature- 250 ºC, Transfer line temperature-230ºC, Ionisation mode: IE at 70eV. The diluted sample was injected by normal mode, and the helium gas flow rate was consistently maintained at 1mL/min.

The National Institute of Standards and Technology (NIST) database was utilised to interpret the mass spectrum obtained from the GC-MS. The unknown component's spectrum was compared to the spectra of known components contained in the NIST library. The names, molecular weights, and structures of the test materials were determined, and the findings were compiled.

RESULTS AND DISCUSSION

Proximate and physicochemical properties of kinnow seed

The seed length, width, and height ranged from 13.14 to 13.42 mm, 5.75 to 6.47 mm, and 4.08 to 4.52 mm, respectively. The weight of 1000

kinnow seeds was 155.04 ± 6.58 g, and the seeds were moderately light yellow in color. The moisture content of the seeds was 39.00 ± 1.07%, and the oil content was found to be 34.00 ± 0.61%. The kinnow seed powder contained protein, fat, fiber, ash, moisture, and carbohydrates at levels of 13.01 ± 0.32%, 28.65 ± 1.06%, 6.00 ± 1.28%, 4.77 ± 0.90%, 14.63%, and 31.96 ± 1.10%, respectively, as shown in Table 1.

According to the literature, the moisture content of seeds was reported to be 42%, and the oil content was approximately 35%. In another study, different values for proximate parameters in citrus species were reported as follows: ash (4.6–5.6%), fibres (5.0–8.5%), proteins (15.9–19.9%), and carbo-hydrates (24.0–31.9%) (Yilmaz & Güneşer, 2017).

Table 1.
Physicochemical characteristics of kinnow peel and kinnow seeds

Parameter	Value
Kinnow peel	
Moisture (%)	75.08 ± 1.13
Ash (%)	2.77 ± 0.05
Fat (%)	1.27 ± 0.09
Water absorption capacity (g w/g	6.96 ± 0.11
Oil absorption capacity (g	3.22 ± 0.09
Swelling index (ml water/ g	22.90 ± 0.06
Solubility (%)	36.05 ± 0.12
Kinnow seed powder	
Moisture content (%)	39.00 ± 1.07
Ash (%)	4.77± 0.90
Fat (%)	28.65 ± 1.06
Protein (%)	13.01 ± 0.32
Carbohydrate (%)	31.96 ± 1.10
Crude fibre (%)	6.00 ± 1.28

Data are presented as mean ± standard deviation of three replicates

Extraction of seed oil

A mechanical press machine was used to extract oil, and 34.00 ± 0.61% yield was observed per 100 g of kinnow seeds.

Physicochemical properties of kinnow seed oils

The smoke point of kinnow seed oil was recorded as 148.0±0.2 °C, the flash point as 151.0±0.05°C, the melting point as 7 °C, and the freezing temperature ranged from -6 °C to -8 °C. In comparison, orange seed oil exhibited slightly higher smoke and flash points, recorded at 149 °C and 151 °C, respectively. The crystallisation of citrus seed oil samples began at an approximate range from -4 °C to -5 °C and was completed between -6 °C and 8 °C, with a melting point of 7 °C. These values for crystallisation and melting temperatures were consistent with findings from a previous study by Anwar et al. (2008).

The results of various chemical characteristics of the extracted kinnow seed oil are presented in Table 2. The observed values were as follows: pH (6.27±0.01), free fatty acid (1.12±0.02), acid value (5.91± 0.64), peroxide value (92.56±1.08), iodine value (1.467±0.002), refractive index (187.20±1.73), saponification value (0.51±0.17), and unsaponifiable matter. In comparison, the chemical characteristics of seed oil extracted from Mausami citrus showed an iodine value of 0.5, a refractive index of 1.4645, a saponification value of 1.8950, an unsaponifiable matter of 0.59%, and a peroxide value of 2.40. Free fatty acid content in cooking oil is typically observed within the range of 0–3% (Yilmaz & Güneşer, 2017). Citrus seed oil is known for its semi-drying properties and high content of both oleic and linoleic acids, making it a valuable source of vegetable oil for culinary use (O'Fallon et al., 2007).

Table 2.
Physicochemical properties of kinnow seed oil

Parameter	Value
Oil yield (%)	34.00 ± 0.61
Smoke point (°C)	148.00 ± 0.2
Flash point (°C)	151.00 ± 0.05
Melting point(°C)	7
Freezing temp (°C)	-6 to-8
Colour L*	48.93 ± 0.118
a*	2.69 ± 0.064
b*	16.01 ± 0.130
pH	6.27 ± 0.01
Acid value (%)	1.12 ± 0.02
Peroxide value	5.91 ± 0.64
Refractive index (20D)	1.47 ± 0.002
Saponification value	187.20 ± 1.73
Unsaponification	0.51 ± 0.17

Data are presented as mean ± standard deviation of three replicates

FT-IR Infrared spectrum of kinnow seeds oil

FT-IR spectrum of kinnow seed oil is shown in Fig. 1. The vibrational bands around 3200 to

3600 cm^{-1} contain flavonoids with aliphatic group and O-H stretching, 3000-3200 cm^{-1} contains flavonoids with aliphatic group and N-H stretching, 2800-3000 cm^{-1} contains phenolics with alkene group and C-H stretching (CH_2–CH_3 contains double and triple of hydrogen), 1630-1700 cm^{-1} contains phenols with alkene group and O-H stretching (Oliveira et al., 2016).

Table 3.
FT-IR Infrared spectrum interpretation of kinnow seeds ol

Area of peak	Assignment
400-500 cm^{-1}	C-OH_3 stretching
500-600 cm^{-1}	O-H stretching
600-900 cm^{-1}	C-H stretching
900-1000 cm^{-1}	C-H stretching
1000- 1140 cm^{-1}	C-H stretching
1000-1200 cm^{-1}	C-H-stretching
1200-1400 cm^{-1}	C-H stretching
1400-1500 cm^{-1}	Ring stretching vibrations
1630-1700 cm^{-1}	Amide I region, O-H stretching C=O
2800-3000 cm^{-1}	C-H stretching C=O, CH_2-CH_3
3000-3200 cm^{-1}	N-H stretching

FT-IR Infrared spectrum interpretation of kinnow seeds oil shown in Table 3.The fatty acid profile of kinnow seed oil was analysed using GC-MS, and the results are detailed in Table 4. A total of 22 fatty acids were identified. Among the saturated fatty acids, hexadecenoic acid was found to be the most prevalent, making up 24.28% of the total area, with a retention time of 35.9 minutes. This was followed by esconic acid, which accounted for 1.12% of the area with a retention time of 42.1 minutes, and stearic acid at 6.59% with a retention time of 38.8 minutes.

The oil was notably rich in unsaturated fatty acids, with 9-octadecenoic acid being the most abundant in this group, contributing 15.6% to the total area and eluting at 38.61 minutes. It was followed by trans-2-hexadecenoic acid.

For comparison, previous studies on citrus seed oils have reported the presence of various fatty acids including lauric (0.39%), myristic (0.43%), palmitic (29.52%), stearic (4.32%), oleic (22.25%), linoleic (33.21%), linolenic (9.56%), and arachidic acid (0.32%) (Moulehi, Bourgou, Ourghemmi & Tounsi, 2012). The GC-MS chromatogram illustrating the fatty acid composition of kinnow seed oil is presented in Fig. 1

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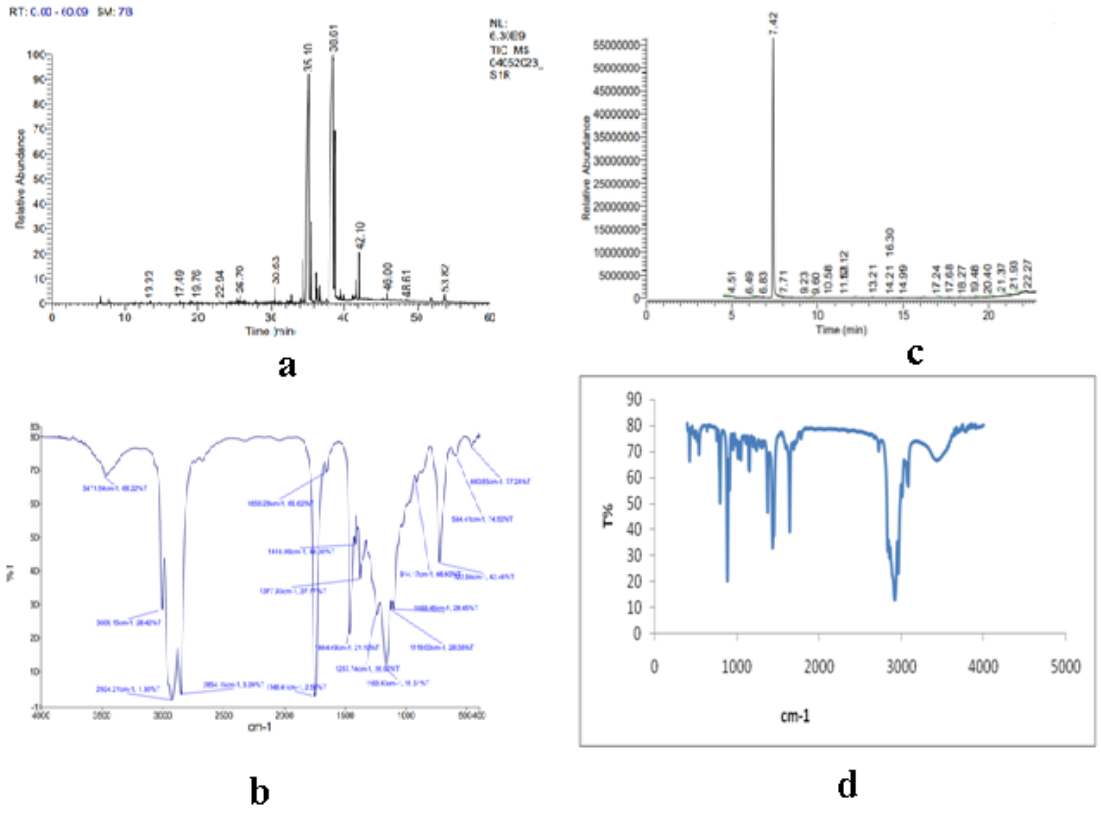

Figure 1. FT-IR spectrum of kinnow seed oil (a) and peel oil (d); GC-MS chromatograph of seed oil (b) and peel oil (c)

Table 4.
Fatty acids profiling of kinnow seeds oil

Compound name	RT	Area (%)	Molecular mass (g/mol)	Probability
1. Dodecanoic acid (lauric)	26.03	0.11	201.31	63.03
2. Methyl-tetradecanoate (myristic)	30.63	0.34	242.4	76.97
3. trans-2-Hexadecenoic acid	32.23	0.05	254.408	6.31
4. Pentadecanoic acid	32.76	0.19	256	2.48
5. Hexadecanoic acid	34.07	0.15	256.42	9.22
6. 9-Hexadecenoic acid	34.41	1.25	254.41	38.02
7. Hexadecanoic acid	35.09	24.28	270	87.50
8. Methyl10-methyl-hexadecanoate	36.22	0.69	270.5	39.01
9. cis-10-Heptadecenoic acid	36.32	0.30	268.4	44.81
10. Heptadecanoic acid	36.75	0.48	270.5	51.26
11. 10-Octadecenoic acid	37.48	0.09	282.461	6.80
12. 9,12-Octadecadienoic acid	38.50	43.94	280.4	6.69
13. 9-Octadecenoic acid	38.61	15.68	282.5	11.02
14. Stearic acid	38.87	6.59	284.5	36.67
15. cis-10-Nonadecenoic acid	39.51	0.21	296.5	17.23
16. Octadecanoic acid, 17-methyl	39.94	0.16	298.5	25.62
17. 6,9,12,15-Docosatetraenoic acid	41.23	0.08	346	6.52
18. 9,12,15-Octadecatrienoic acid	41.33	0.11	278.4	18.96
19. cis-11-Eicosenoic acid	41.69	0.44	310.51	24.30
20. Eicosanoic acid	42.10	1.12	312.53	78.52
21. Docosanoic acid	46.00	0.20	340.6	41.91
22. Tetracosanoic acid	51.88	0.16	368.637	34.01

RT – retention time

Proximate and physicochemical properties of kinnow peel

Table 1 shows the proximate composition of fresh kinnow peel. The moisture content was found to be 75.08%, with crude fat at 1.27% and ash at 2.77%. In the case of dried kinnow peel, the water retention capacity (WRC) was measured at 6.96 g of water per gram of dry matter, while the oil retention capacity (ORC) was 3.22 g of oil per gram of dry matter. The swelling index was recorded as 22.90 ml of water per gram of dry matter, and solubility was noted at 36.05%.

These findings are in line with earlier reports on fresh orange (*Citrus aurantium*), various citrus cultivars, and kinnow mandarin processing waste (Garau et al., 2007; Malla, Rastogi, Sharma, Ishfaq & Farooq, 2015; Rafiq, Singh & Gat, 2019). A comparable ash content of 2.495% was reported for *Citrus maxima* fruit peel in a separate study (Ani & Abel, 2018). Similarly, earlier work on mechanically dried kinnow peel showed nearly parallel values, with a WRC of 7.21 g/g DM, an ORC of 2.29 g/g DM, a swelling index of 23.78 ml/g DM, and solubility at 37.33% (Sharma, 2017).

Essential oil extraction yield

The hydrodistillation method yielded a maximum of 2.10 ± 0.05% essential oil. In terms of oil recovery, it was observed that 2 mL of oil was extracted per 100 grams of dried shad orange and mosambi peels, while lemon peel produced about 1.5 mL per 100 grams (Aruna, Hemalatha, Vellaikumar, Kanchana & Kumutha, 2022).

Supporting data from a separate study showed that the average essential oil yield from lemon peels was 1.56%, whereas orange peels produced a higher yield of 3.55% (Zeleke, 2022).

Similar results have been observed by other researchers, aligning well with the findings of this study (Tran, Nguyen, Le, Phong & Long, 2021). The composition of citrus essential oils is known to fluctuate based on several factors,

including the chemical nature of the components, environmental conditions, soil quality, and the timing of harvest. In a separate experiment conducted under controlled conditions, Toan and colleagues extracted essential oil from *Citrus aurantifolia* peel and achieved a yield of 2.1% (Toan, Truc, Le, Quyen & Tran, 2020).

Fourier Transform Infrared Spectroscopy (FT-IR) of kinnow seed oil

Fourier Transform Infrared (FT-IR) spectroscopy remains one of the most reliable tools for identifying functional groups in organic compounds. In this study, Fig. 1 and Table 5 present the infrared spectra and notable absorption bands found in kinnow peel oil extracted through hydrodistillation, analysed in the 4000–400 cm^{-1} range.

The FT-IR results confirmed the presence of D-limonene by identifying specific vibrational patterns: a band at 887 cm^{-1} attributed to out-of-plane bending of the terminal methylene group, bands between 1436–1452 cm^{-1} related to C–H asymmetric and symmetric bending, and a distinct peak at 1644 cm^{-1} corresponding to C=O stretching vibrations. Comparable absorption patterns, with slight differences in intensity, have also been observed in the FT-IR profiles of various other essential oils. These findings were further supported by GC-MS analysis, reinforcing the identification of D-limonene in the sample and also supported by Sandhu et al. (2021).

GC-MS analysis of kinnow peel essential oil

GC-MS analysis identifies a wide range of compounds in the essential oil. The chromatogram, as shown in Fig. 1 and detailed in Table 6, displayed several peaks, each indicating the presence of a distinct chemical compound..

In kinnow peel essential oil, D-limonene emerged as the most dominant compound, with a retention time of 7.42 minutes, followed by carvacrol. These findings are consistent with previous research by Giatropoulos et al. (2012), who reported similar essential oil components in different citrus species. Further supporting this, a study by Ferhat, Meklati, Smadja and Chemat (2006) also found that D-limonene was the major constituent in essential oil derived from orange peel.

Table 5.
FT-IR Infrared spectrum interpretation of kinnow seed oil

Link Present	**X (cm^{-1})**	**T(%)**
N-H primary and secondary amines and amide stretch,	3435.68	66.61
N-H primary and secondary amines and amide stretch, Alkenes stretch	3084.25	56.69
N-H primary and secondary amines and amide stretch, C-H Alkenes stretch	3047.26	64.61
N-H primary and secondary amines and amide stretch	3011.17	52.75
C-H, C-H Alkanes stretch	2965.96	23.32
C-H Alkanes stretch	2921.31	13.10
C-H Alkanes stretch	2856.91	29.16
C-H Alkanes stretch	2835.72	31.83
C-H Aldehyde	2726.26	70.21
C=O Amide	1694.21	70.91
C=C Alkene	1644.89	39.27
-CH_3 bend	1452.45	37.66
-CH_3 bend	1376.67	46.68
C-O Alcohols, ether, ester, carboxylic acid, anhydrides	1241.42	70.50
C-O Alcohols, ether, ester, carboxylic acid, anhydrides	1148.12	63.21
C-O Alcohols, ether, ester, carboxylic acid, anhydrides	1051.54	66.74
C-O Alcohols, ether, ester, carboxylic acid, anhydrides	1016.36	67.44
Aromatic out-of-plane bend	956.83	70.73
Aromatic out-of-plane bend	914.28	55.19
Aromatic out-of-plane bend	887.48	20.27
Aromatic out-of-plane bend	797.81	50.25

Table 6.
Characterization of kinnow peel essential oil by GC-MS

RT (min)	Compound name	Peak area (%)
6.39	(1R)-2,6,6-Trimethylbicyclo[3.1.1]hept-2-ene	0.38
6.28	à-Pinene	1.33
6.83	3-Carene	0.33
7.13	á-Myrcene	1.43
7.36	Octanal	0.69
7.42	D-Limonene	92.04
9.11	Linalool	0.36
10.78	3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-, terpinen-4-ol	0.40
11.02	à-Terpineol	0.49
11.56	2-Cyclohexen-1-ol, 2-methyl-5-(1-methylethenyl), Carveol	0.47
17.68	Heptasiloxane	0.10
17.96	(6,8-Bis-hydroxymethyl-4-isopropyl -7-methylene-bicyclo[3.2.1]oct-1-yl) –methanol	0.10
20.08	2,6,11-Dodecatrienal, 2,6-dimethyl-10-methylene	0.55
22.22	Benzenehexaethanol, hexaacetate	1.05

RT – retention time

CONCLUSION

The results of this study indicate that kinnow seeds have the potential to be a rich source of nutrients. The oil extracted from the seeds contains a balanced mix of polyunsaturated and saturated fatty acids. Kinnow seed oil has drawn increasing interest, not only as a vegetable oil source but also for its reported anticancer and antimicrobial properties.

As the world's population expands and industrial development accelerates, the demand for vegetable oils and fats has surged, currently amounting to roughly 125 million metric tonnes annually. Many countries rely heavily on imports to meet this demand, resulting in high costs. To address this challenge, it is important to explore alternative sources of vegetable oils that also offer health benefits and functional properties for both the food and oleochemical industries.

According to the FDA, essential oils from the vast majority of citrus species are "Generally Recognised as Safe" (GRAS) food additives. In addition, citrus essential oil has antibacterial, antifungal, and insecticidal properties with a broad spectrum.

Future recommendations

This study emphasises the promising potential of kinnow fruit waste as a valuable resource for creating sustainable products. However, unlocking its full potential will require further research. Future efforts should aim for the complete utilisation of all kinnow processing by-products—such as pulp, membranes, and juice-processing effluents—moving toward a zero-waste model. To boost the extraction of beneficial compounds while reducing environmental impact, researchers should explore eco-friendly and cutting-edge techniques like supercritical CO_2 extraction, ultrasound-assisted extraction, and the use of deep eutectic solvents.

Innovative value-added products, in-cluding bioplastics, dietary fibre supplements, and natural preservatives, could enhance both economic viability and market reach. To assess the practicality of these applications, conducting life cycle assessments (LCA) and techno-economic analyses is essential. In addition, further in vivo and clinical research is needed to confirm the safety and health benefits of kinnow-derived compounds.

It’s also impor-tant to explore how factors like variety, gro-wing conditions, and harvest timing affect the waste's composition and usefulness. Standardising sampling protocols and conducting comparative studies across differrent growing regions can help address this variability.

AUTHOR CONTRIBUTIONS

Conceptualization, M.K. and K.Y.; Methodology, M.K. and K.Y.; Investigation, formal analysis, validation, writing-original draft pre-

paration, J.C. and A.C.; Writing-review and editing, K.Y.; Supervision, M.K.

DATA AVAILABILITY STATEMENT

Data contained within the article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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VALORIZACIJA OTPADA OD PLODOVA MANDARINE – ODRŽIVI PRISTUP ZAŠTITI ŽIVOTNE SREDINE

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Sažetak: Tokom prerade plodova mandarine u sok, oko 30–34% kore ploda i u proseku 20–25 semenki nastaje kao otpad. Shodno tome, ova studija ima za cilj da utvrdi elementarni sastav, hemijski sastav i sadržaj ulja semenki i kore lokalno uzgajanih mandarina.
Esencijalno ulje iz kore mandarine ekstrahovano je hidrodestilacijom, dok je ulje iz semenki dobijeno hladnim ceđenjem. Karakterizacija oba ekstrahovana ulja izvršena je pomoću FT-IR i GC-MS analiza. Hemijska analiza praha od semena mandarine pokazala je sledeći sastav: proteini: 13.00 ± 0.32%, masti: 28.65 ± 1.06%, vlakna: 6 ± 1.28%, pepeo: 4.771 ± 0.90%, vlažnost: 14.63%, ugljeni hidrati: 31.96 ± 1.10%. Tačka dimljenja ulja od semenki kinnowa iznosi 148 °C, dok su ostali parametri sledeći: pH: 6.26 ± 0.01, kiselinska vrednost: 1.125 ± 0.02, peroksidna vrednost: 5.91 ± 0.64, jodna vrednost: 92.56 ± 1.08, refraktivni indeks: 1.46 ± 0.002, sapunifikaciona vrednost: 187.2 ± 1.73, nesapunjive materije: 0.51 ± 0.17. Sadržaj vlage, sirovih masti i pepela u svežoj kori mandarina iznosi 75.08%, 1.27%, and 2.77%, respektivno. Kapacitet zadržavanja vode (WRC), kapacitet zadržavanja ulja (ORC), indeks bubrenja i rastvorljivost osušene kore mandarine iznose: 6.96 g vode /g s.m., 3.22g ulje/g s.m., 22.90 ml vode/g s.m. i 36.05%, respektivno. GC-MS analizom je utvrđeno da je heksadecenska kiselina najzastupljenija zasićena masna kiselina u ulju od semena mandarine, sa površinom od 24.28% i vremenom zadržavanja 35.9 min, zatim eskonična kiselina sa 1.12% površine, 42.1 min vremena zadržavanja, i stearinska kiselina sa 6.59% površine i vremenom zadržavanja 38.8 min. Najzastupljenije jedinjenje u esencijalnom ulju kore mandarine bio je D-limonen, sa vremenom zadržavanja 7.42 min, identifikovan GC-MS analizom.

Ključne reči: *Citrus reticulata Blanco, esencijalno ulje kore, ulje iz semena, GC-MS, FT-IR*

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