

Article

Not peer-reviewed version

Utilization of Biomass Waste from Citrus Fruits for the Production of Essential Oils

Quilo Esmeralda Catucuamba , Jimmy Alba Lechón , [Bayas Favian Morejón](#) , [Orlando Meneses Quelal](#) ^{*} , [Juan Gaibor Chávez](#)

Posted Date: 9 February 2026

doi: 10.20944/preprints202602.0587.v1

Keywords: essential oils; citrus peel; fractional distillation; kinetic modeling; Monod model; circular economy; limonene; biorefinery



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a [Creative Commons CC BY 4.0 license](#), which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Disclaimer/Publisher's Note: The statements, opinions, and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions, or products referred to in the content.

Article

Utilization of Biomass Waste from Citrus Fruits for the Production of Essential Oils

Quilo Esmeralda Catucuamba ¹, Jimmy Alba Lechón ¹, Bayas Favian Morejón ¹, Orlando Meneses Quelal ^{2,*} and Juan Gaibor Chavez ¹

¹ Universidad Estatal de Bolívar (UEB). Carrera de Ingeniería Agroindustrial. Facultad de Ciencias Agropecuarias, Recursos Naturales y del Ambiente. Guaranda-Ecuador

² Universidad Politécnica Estatal Del Carchi (UPEC). Carrera de Alimentos. Facultad de Industrias Agropecuarias y Ciencias Ambientales. Tulcán- Ecuador

* Correspondence: orlando.meneses@upec.edu.ec

Abstract

The valorization of citrus peel waste represents a fundamental pillar for developing a circular bioeconomy within the agri-food sector. This study comprehensively evaluated the biorefinery potential of ten citrus varieties, encompassing mandarin (*Citrus reticulata criolla*, *Citrus nobilis* Loureiro, *Citrus tangerina*, *Citrus unshiu*), lemon (*Citrus aurantifolia swingle*, *Citrus limonia*, *Citrus limonum*, *Citrus latifolia*), and grapefruit (*Citrus paradisi*, *Citrus paradisi* Macfad) from the Bolívar province of Ecuador. The residual biomass was characterized through proximate and elemental analyses, revealing significant variability in moisture, ash, and volatile solids content among varieties. Essential oil extraction was optimized using fractional distillation, systematically evaluating the effect of maceration time at two levels. Results demonstrated that *Citrus nobilis* Loureiro exhibited the highest extraction yield, while grapefruit varieties showed the most pronounced response to extended maceration time. Gas chromatography coupled with mass spectrometry confirmed limonene as the predominant component across all varieties, with grapefruit essential oils achieving exceptional purity exceeding ninety percent. The chemical profiles revealed statistically significant intervarietal differences in monoterpene distribution, establishing distinctive chemotaxonomic patterns. The principal scientific contribution of this work lies in the advanced kinetic modeling approach, wherein seven mathematical models were rigorously evaluated to describe extraction dynamics. The Monod model demonstrated superior predictive capacity with coefficients of determination exceeding 0.99, providing mechanistically meaningful parameters for process optimization and industrial scaling. This integrated analytical framework, combining compositional characterization with predictive kinetic modeling, positions these agro-industrial residues as sustainable sources of high-quality essential oils for food, pharmaceutical, and cosmetic applications under circular economy principles.

Keywords: essential oils; citrus peel; fractional distillation; kinetic modeling; Monod model; circular economy; limonene; biorefinery

1. Introduction

Citrus fruits, renowned for their wealth of bioactive and aromatic compounds, have been the subject of extensive scientific research thanks to their versatility and application in diverse industries, including food, pharmaceuticals, and cosmetics (Sharma et al., 2022). Within this vast landscape, citrus peel has emerged as an exceptionally rich source of essential oils with remarkable therapeutic and sensory properties (Gaur et al., 2022). In industrial settings, minimizing raw material losses and reducing waste generation are crucial imperatives for mitigating negative environmental impact (Chen et al., 2018). Byproducts, including peels, seeds, and residual membranes of citrus fruits, represent approximately 50% to 60% of the total fruit weight in citrus processing operations (Mahato

et al., 2019). In this context, the use of biomass waste from citrus fruits in obtaining essential oils has sparked growing interest in the scientific community, due to its promise to mitigate the accumulation of organic waste and promote the sustainable production of highly valuable compounds (Ortiz-Sanchez et al., 2023).

The use of citrus fruit waste to obtain essential oils not only contributes to reducing organic waste but also offers the possibility of generating additional income for the agricultural industry and improving the environmental sustainability of citrus production operations (Mahato et al., 2021). This practice represents an innovative approach to addressing the global challenge of agricultural waste management while taking advantage of the valuable compounds present in citrus peel. As noted by Pomoni et al. (2024), valorizing this waste stream not only mitigates the environmental impacts associated with its disposal but also generates new economic opportunities for agricultural producers. Furthermore, several studies have demonstrated the potential of essential oils obtained from citrus waste in a wide range of industrial applications, such as the food, pharmaceutical, and cosmetic industries (Wedamulla et al., 2022). In this context, ongoing research in this field is crucial not only for optimizing the extraction and valorization processes of these compounds but also for better understanding their environmental and economic impact throughout the entire citrus supply chain (Nirmal et al., 2023).

The production of essential oils from citrus peels benefits greatly from research on the bioactive compounds present in these peels. Numerous studies have focused on exploring potential applications of citrus peel in the food industry, given its richness in various active components such as dietary fiber, pectin, proteins, pigments, flavonoids, and essential oils (Huang et al., 2020). Studies conducted by Zárate et al. (2020) have explored these compounds and developed effective extraction techniques to obtain them from citrus peel. Furthermore, research such as that of Liu et al. (2021) and Panwar et al. (2021) has demonstrated the wide range of applications of these bioactive compounds in various industries. These applications address a variety of biological properties, such as antioxidant, antimicrobial, anticancer, anti-inflammatory, and antidiabetic activities (Dai et al., 2019). This knowledge supports and enhances the production of essential oils from citrus peels by providing a solid scientific basis for the selection of compounds and more effective extraction techniques (Dash et al., 2019).

The extraction of essential oils from citrus fruit biomass waste can be achieved through various techniques, such as hydrodistillation (Díaz-Reinoso et al., 2023), solvent extraction, and cold pressing (Basak & Annapure, 2022). Hydrodistillation is an economical and efficient process for obtaining essential oils, in which saturated steam under pressure is used to extract volatile compounds from the plant material (Kim et al., 2022). Solvent extraction involves the use of organic liquids to dissolve the desired compounds, while cold pressing uses mechanical pressure to extract the liquid from the plant material without the use of heat (Chiou et al., 2019). Among the various extraction alternatives, fractional distillation is emerging as a promising application, widely documented in the scientific literature. This technique offers numerous advantages, as it reduces the boiling point of the essential oil within the column. This temperature reduction mitigates the degradation of essential components, minimizing the adverse effects of high temperatures (Perini et al., 2017).

The main objective of this work was to comprehensively evaluate the valorization potential of the peels of ten citrus varieties from the Bolívar province through the extraction and characterization of their essential oils. The specific objectives were: (1) to determine the proximate and elemental composition of the peels, (2) to evaluate the effect of maceration time (8 and 12 h) on the extraction yield, (3) to characterize the chemical composition of the essential oils using GC-MS, and (4) to model the extraction kinetics using seven mathematical models to identify the best-fit model and predict the maximum yield. The hypothesis suggests that the botanical variety and the maceration pretreatment significantly influence the extraction kinetics and efficiency. This study is distinguished by being the first to integrate a comprehensive kinetic analysis with multiple models (Monod, Teissier, Haldane, Gompertz, Moser, Powell, Logistic Law) for the extraction of essential oils from such a diverse set of

citrus varieties from a high Andean region, providing fundamental data for the design of biorefinery processes based on experimental evidence and predictive modeling

2. Materials and Methods

2.1. Plant Material

For this study, samples of four mandarin varieties were selected and collected: *citrus reticulata* criolla (CRC), *citrus nobilis* Loureiro (CNL), *citrus tangerina* (CT) and *citrus unshiu* (CU); as well as samples of four varieties of lemon: *citrus aurantifolia* swingle (CAS), *citrus limonia* (CL₁), *citrus limonum* (CL₂) and *citrus latifolia* (CL₃). In addition, samples of two grapefruit varieties were collected: *citrus paradisi* (CP) and *Citrus paradisi* Macfad (CPM). These fruits were obtained from the cantons of the province of Bolívar, specifically from Echea (1°26'00"S 79°16'00"W), Caluma (1°38'00"S 79°15'00"W) and Las Naves (1°17'00"S 79°18'00"W).

2.2. Experimental Methodology

2.2.1. Sample Preparation

The citrus peels were cut into 1 cm² pieces, weighing 300 g for mandarin varieties and 200 g for lemon and grapefruit varieties. These samples were placed in glass containers for maceration. 250 mL of distilled water and 0.7% NaCHO₃ were added per 100 g of sample. Once the plant material and reagents were placed in the containers, they were sealed and shaken for 1 minute to homogenize the contents. The containers were then left to stand for 8 to 12 hours.

2.2.2. Analysis of Citrus Peel

Proximate and elemental analysis of citrus fruit peels was performed to determine their chemical composition. The proximate analysis determined moisture content (UNE- EN ISO 18134-2:2017), ash content (UNE-EN ISO 18122:2016), and total volatiles (UNE-EN ISO 18123:2015). The elemental analysis measured the percentage of carbon, hydrogen, nitrogen, and sulfur according to UNE-EN ISO 15104.

2.2.3. Extraction of the Essential Oil

Biobase brand fractional distillation apparatus was used. This apparatus consists of a 2000 mL heating mantle that reaches a maximum temperature of 380 °C, a 2000 mL distillation flask, a 10-plate fractionating column, a distillation head or T-piece, an adapter with a mercury thermometer, a straight condenser, a distillation tail, an Erlenmeyer flask, and a separatory funnel. All tests were performed at a temperature of 78–85 °C, a mass flow rate of 9.03–16.81 mL /s, a pressure of 0.973 atm, and a time of 120 minutes. A 10 mL graduated cylinder was used to measure the volume. The samples were stored in amber glass vials, which were then wrapped in aluminum foil to prevent exposure to light and kept at 12 °C until further chemical analysis.

Essential oil density

To determine the density of the essential oils of mandarin, lemon, and grapefruit, the samples were placed in a 10 mL pycnometer at a temperature of 20 °C. The density was calculated using the following equation 1:

$$\rho = \frac{m_2 - m_1}{v} \quad \text{Eq. 1}$$

Where,

ρ : density of the essential oil, g/ mL

m_1 : mass of the empty pycnometer, g

m_2 : mass of pycnometer + essential oil, g

v : volume of essential oil, mL

pH of essential oil

The pH measurement of the essential oil samples was performed using the HANNA brand pH meter.

GC-MS analysis of the essential oil

The chemical composition of the essential oils of mandarin, lemon, and grapefruit was identified using a gas chromatograph (GC THERMO SCIENTIFIC-TRACE 1300) coupled to a single quadrupole mass spectrometer (ISQ 7000) and a DB-5MS column (30 m long, 0.25 mm internal diameter, and 0.25 μm thick). The injector temperature was maintained at 230 $^{\circ}\text{C}$ using split injection mode with an injection volume of 1 μl . The oven temperature program was from 50 $^{\circ}\text{C}$ to 230 $^{\circ}\text{C}$ at a rate of 3 $^{\circ}\text{C}/\text{min}$. The total running time was 66 minutes.

For sample preparation, 3 μL of each essential oil was weighed into amber chromatography vials and 1 mL of nonane standard solution with cyclohexane was added.

Experimental yield of essential oil

In this study, different mathematical models were applied to determine the yield of essential oil extracted using fractional distillation. The yield of essential oils was estimated experimentally using the percentage yield equation (P. T. Dao et al., 2022) (Eq. 2).

$$Y = \frac{v}{W} * 100\% \quad \text{Eq. 2}$$

Where,

Y: experimental yield of the essential oil (% v/W)

v: mass of essential oil (mL)

W: mass of the peel of the citrus fruits used (g)

Equation (2) allowed the calculation of performance values obtained from 10-minute intervals.

Mathematical modeling of the yield and extraction rate of essential oils

In this study, different mathematical models were used, which were fitted to the experimental performance values. Seven models were used to determine which one provided the best fit.

Monod mathematical model

$$Y = \frac{Y_{max} * t}{k + t} \quad \text{Eq. 3}$$

Teissier's mathematical model

$$Y = Y_{max} * \left(1 - e^{-\frac{t}{k}}\right) \quad \text{Eq. 4}$$

Haldane's mathematical model

$$Y = \frac{Y_{max} * t}{k + t + t^2 * k_i} \quad \text{Eq. 5}$$

Gompertz mathematical model

$$Y = Y_{max} * e^{(-e^{-k*t+b})} \quad \text{Eq. 6}$$

Moser's mathematical model

$$Y = \frac{Y_{max} * t^n}{k + t^n} \quad \text{Eq. 7}$$

Powell's mathematical model

$$Y = \frac{Y_{max} * t}{k + t + k_i} \quad \text{Eq. 8}$$

Mathematical model of Logistic Law

$$Y = Y_{max} * \left(1 - \frac{k}{t}\right) \quad \text{Eq. 9}$$

Where,

A_{nd} : essential oil yield
 Y_{max} : maximum yield, %
 k : kinetic constant, min
 k_i : constant, min⁻¹
 t : time, min
 b : constant
 n : constant
 t : time, min

3. Results and Discussion

3.1. Chemical Composition of the Peel of the Citrus Fruits Mandarin, Lemon and Grapefruit.

3.1.1. Proximal Analysis

The results derived from the proximate and elemental analysis of mandarin, lemon, and grapefruit peels are summarized in **Table 1**. The proximate analysis of lemon, mandarin, and grapefruit peels provides a comprehensive evaluation of their chemical composition, including parameters such as moisture, ash, and total volatiles. A notable variability in moisture percentages (ω) emerged among the different citrus peel samples, with figures fluctuating approximately between 66% and 86%. This phenomenon suggests disparities in water-holding capacity among the various mandarin, lemon, and grapefruit varieties. In the lemon moisture results, variations were observed among the different varieties tested, with percentages ranging from 79.94% to 86.21%. Previous studies, such as those by Pham et al. (2020) and Ghanem et al. (2012), have shown discrepancies in these values, reporting measurements that ranged between 60.96% and 75.04%. In contrast, the moisture analyses in this study for mandarin varieties showed values ranging from 74.90% to 79.48%. Similarly, Ghanem et al. (2012) and Marey and Shoughy (2016) reported moisture percentages of 79.5% and 79.6%, respectively. Abdel Wahab et al. (2018) and Indrastuti et al. (2020) reported moisture values of 72.10% and 82.92% for mandarin peel (*Citrus tangerina*). In other research, Rafiq et al. (2019) reported a moisture value of 77.47% for mandarin peel (*Citrus unshiu*). Finally, Abdullah and Abdul (2018) reported values between 71.4% and 72% in different mandarin varieties tested. Regarding the results of the grapefruit peel moisture analysis in this study, the moisture content of *Citrus paradisi* was 69.787%, and that of *Citrus paradisi* Macfad was 66.049%. Mohamed and Wassila (2015) reported higher values of 75.25% for *Citrus paradisi* grapefruit and 75.37% for *Citrus paradisi* Macfad. Rahman et al. (2018), on the other hand, obtained a moisture content of 80.59% for grapefruit peel. Regarding ash (As) percentages, these exhibited relatively modest levels in all samples, ranging between 4% and 5.5%. The ash content of the different lemon varieties was: *Citrus aurantifolia* Swingle 4.55%, *citrus limonia* 5.48%, *citrus limonum* 4.40% and *citrus latifolia* 4.99%. Janati et al. (2012) and Elghfar et al. (2016) reported values of 6.26% and 6.58%, respectively for the *citrus aurantifolia* variety Swingle. Jiménez et al. (2021) reported values of 3.69% in the *Citrus latifolia* variety. On the other hand, Akhtar et al. (2021) reported an ash content of 3.39% for the *Citrus limonum* variety. In contrast, for mandarin citrus fruits, the ash content yielded results of 4.39% for the *Citrus reticulata* criolla variety and 5.37% for *Citrus nobilis*, 5.06% for *Citrus tangerina*, and 5.17% for *Citrus unshiu*. Studies conducted by Balderacchi et al. (2022), Adeyanju et al. (2022), and Xu et al. (2017) obtained percentages of 0.48%, 3.96%, 2.88%, and 2.23%, respectively. In another study, Green et al. (2014) reported percentages of 14.32%. Regarding grapefruit, the ash values were 4.436% for *Citrus paradisi* and 4.265% for *Citrus paradisi* Macfad. Kohajdová et al. (2013), in a study on the characteristics of *citrus paradisi* Macfad peel, reported values of 3.55%, while Edet et al. (2016) reported values of 3.97%. On the other hand, Ahmad et al. (2016) reported values of 6.24%.

The percentage of VS in the lemon varieties was as follows: *Citrus aurantifolia* Swingle, 84.45%; *Citrus limonia*, 80.04%; *Citrus limonum*, 82.74% and 87.93%. In contrast, the VS percentages for mandarin were 82.33% for *Citrus reticulata* criolla and 88.03% for *Citrus nobilis* Loureiro, 90.25% for

Citrus tangerina, and 88.22% for *Citrus unshiu*. Yankovsky et al. (2019) reported lower VS values of 80.87% and 80.41% for the peel of Creole mandarin. Shin et al. (2021) reported a VS value of 82.05% for tangerine peel. For unshiu mandarin peel, Wu et al. (2019) reported a similar VS value of 88.14%. Finally, for grapefruit, VS values of 91.861% and 92.893% were obtained for *Citrus paradisi* Macfad. Cheong et al. (2011) reported 97.96% VS for red grapefruit, while Esmaeili et al. (2013), in their research on grapefruit peel, obtained 97.4% VS. The variation among results could be attributed to soil type, grapefruit variety, season, degree of maturity, and environmental conditions.

Table 1. Proximate and elemental analysis of mandarin, lemon and grapefruit varieties.

Material vegetable	Proximal			Elementary			
	ω (%)	Ace (%)	VS (%)	C (%)	H (%)	N (%)	S (%)
CRC	77.92	4.40	82.33	39.41	6.50	0.71	0
CNL	79.48	5.37	88.04	39.32	6.52	0.73	0
CT	74.90	5.06	90.25	39.03	6.09	0.75	0
CU	78.27	5.17	88.22	39.36	6.45	0.72	0
CAS	83.30	4.55	84.45	42.00	6.30	0.90	0
CL ₁	79.94	5.48	80.07	42.07	6.31	0.94	0
CL ₂	86.21	4.44	82.76	42.06	6.37	0.95	0
CL ₃	82.76	4.99	87.93	42.03	6.35	0.91	0
CP	69.79	4.44	91.86	41.38	6.36	0.71	0
CPM	66.05	4.27	92.89	41.43	6.38	0.71	0

Note: VS (volatile solids), C (carbon), H (hydrogen), N (nitrogen), S (sulfur), As (ash), yw (moisture), *Citrus reticulata* criolla (CRC), *Citrus nobilis* Loureiro (CNL), *citrus tangerina* (CT) and *citrus unshiu* (CU), *citrus aurantifolia* swingle (CAS), *citrus limonia* (CL₁), *citrus limonum* (CL₂), *citrus latifolia* (CL₃), *citrus paradisi* (CP) and *Citrus paradisi* Macfad (CPM).

3.1.2. Elementary Analysis

Regarding the elemental composition, the basic constituents of organic matter, a notable consistency was observed in the values of carbon (C), hydrogen (H), and nitrogen (N); however, sulfur (S) was not present in all analyzed samples. In mandarin citrus fruits, Chiodo et al. (2017) reported values of 42.9% for C, 6.3% for H, 1.3% for N, and 0.1% for S. Diaz et al. (2022) obtained values of 42.1% for C, 1.3% for H, 0.77% for N, and 0.05% for S. In other studies, conducted by Barnossi et al. (2021) and Rojas & Flórez (2019), C values of 56% and 49.14% were reported, respectively. Similarly, the aforementioned authors reported H values of 6.02% and 1.3%, respectively. Tamelová et al. (2019) reported values of 39.72% and 1.64% for C and N, respectively, and a value of 5.89% for H. In grapefruit peel varieties, Tamelová et al. (2018) obtained values of 14.26% for C, 1.80% for H, and 0.36% for N. Finally, Rojas & Flórez (2019) found values of 48.20% for C and 6.02% for H in lemon varieties. In other studies conducted by Adeniyi et al. (2019), values of 1.27% for N and 0.19% for S were recorded; these values are lower than those obtained by Chiodo et al. (2017), who reported 1.3% for N and 0.1% for S. Meseldzija et al. (2019), for their part, reported values of 0.83% for N and 0% for S.

3.2. Extraction of the Essential Oil from the Citrus Fruits Used

The results of essential oil extraction using 8- and 12-hour maceration (Table 2) show quantifiable patterns that integrate statistical aspects and scientific principles of secondary metabolite extraction. Statistical analysis of the data reveals an overall increase in extraction yield with increasing maceration time, with an average change of 0.207% and a mean percentage improvement

of 14.77%. This trend aligns with the kinetic principles of extraction, where time is a determining factor in the diffusion of compounds from plant matrices (Gori et al., 2021).

Table 2. Extraction of essential oils from mandarin, lemon and grapefruit by maceration of 8 and 12 hours.

Variety	And (8h) %	And (12h) %	ΔY (%)	Efficiency	ρ (8h) g/mL	ρ (12h) g/mL	$\Delta \rho$	pH (8h)	pH (12h)	ΔpH
CRC	1.5	1.79	19.30	Moderate	0.84	0.84	0.00	5.12	4.87	-0.25
CNL	2.43	2.91	19.80	Moderate	0.83	0.84	0.01	4.63	5.48	0.85
CT	1.81	1.71	-5.50	Stable	0.84	0.83	-0.01	4.16	5.26	1.10
CU	2.53	2.61	3.20	Stable	0.83	0.83	0.00	4.98	4.94	-0.04
CAS	0.83	0.97	16.90	Moderate	0.85	0.85	0.00	4.42	4.43	0.01
CL1	0.67	0.56	-16.40	Low	0.85	0.85	0.00	4.43	4.43	0.00
CL2	0.69	0.81	17.40	Moderate	0.85	0.85	0.00	4.43	4.42	-0.01
CL3	0.72	0.84	16.70	Moderate	0.86	0.86	0.00	4.42	4.43	0.01
CP	1.15	1.67	45.20	High	0.85	0.84	-0.01	4.45	4.45	0.00
CPM	0.84	1.18	40.30	High	0.85	0.85	0.00	4.33	4.33	0.00

Note: ΔY = Percentage change in yield; $\Delta \rho$ = Change in density; ΔpH = Change in pH. Efficiency classification based on percentage change: High (>30%), Moderate (10-30%), Stable (-5% to 10%), Low (< -5%).

The moderate negative correlation observed between the initial yield $Y(8h)$ and the percentage change ($r = -0.653$) suggests that varieties with lower initial essential oil concentrations tend to show greater relative improvements when the extraction time is extended. This phenomenon can be explained by kinetic models where the driving force (concentration gradient) is maintained for a longer time in matrices with lower initial concentrations, allowing for continuous extraction (Dulo et al., 2023). Conversely, in varieties such as CNL and CU with high initial yields, the system reaches equilibrium more quickly, resulting in smaller marginal improvements.

The high correlation between yields at 8 and 12 hours ($r = 0.973$) indicates consistency in the efficiency ranking among varieties, with CNL maintaining the highest absolute yield (2.91%) followed by CU (2.61%). This consistency suggests that intrinsic factors of each variety, such as the density and distribution of essential oil glands in the flavedo, are primary determinants of extraction potential (Šafranko et al., 2023). Histological studies have shown that varieties like CNL exhibit a higher density of schizogenous glands, which facilitates the release of volatile compounds during maceration (Benedetto et al., 2023).

The cases with the greatest improvement (CP: +45.2%, CPM: +40.3%) represent significant opportunities for industrial optimization. These varieties show a particularly favorable response to the extended time, which could be attributed to specific membrane permeability characteristics or the presence of precursors that require prolonged times for complete hydrolysis and release (Agustí et al., 2025). In contrast, the observed decrease in CL1 (-16.4%) could be related to degradation or chemical recombination phenomena that warrant further investigation (X. Li et al., 2025).

The remarkable stability of the physicochemical parameters (average $\Delta \rho = 0.002$ g/mL, average $\Delta pH = 0.162$ units) suggests that the basic chemical composition of the essential oils does not change significantly with extraction time. This stability is consistent with previous studies reporting high consistency in physical parameters during maceration extractions, indicating that the qualitative profile remains relatively constant (Mori-Mestanza et al., 2025).

From an industrial applications perspective, integrated statistical-scientific analysis provides a quantitative basis for optimization decisions. Varieties classified as "high improvement" represent ideal candidates for processes where extraction time can be optimized to maximize yields, while

varieties with high initial efficiency, such as CNL and CU, are preferable when cycle time is critical (Sun et al., 2020). This time-response-based classification approach provides a systematic framework for varietal selection based on specific production objectives.

The synergy between statistical analysis and scientific rigor in this study contributes to the field of plant metabolite extraction by providing a quantitative framework for evaluating differential responses to extraction time. This integrated approach allows not only the description of trends but also the identification of underlying mechanisms and variety-specific optimization opportunities, advancing towards more efficient and sustainable extraction protocols (Yan et al., 2022).

3.3. Chemical Analysis of the Essential Oil of the Citrus Fruits Used

Detailed chemical analysis of citrus essential oils (Tables 3, 4, and 5) reveals complex compositional patterns that go beyond mere component identification, providing crucial quantitative information on intervarietal variability and its implications for functional properties. As presented in Table 3, statistical analysis of the data demonstrates that limonene is the main component in all varieties analyzed, with mean values of $84.99\% \pm 7.87\%$ in mandarins (coefficient of variation, CV = 9.26%), $74.36\% \pm 9.53\%$ in lemons (CV = 12.82%), and $91.44\% \pm 0.94\%$ in grapefruits (CV = 1.03%). This statistically significant compositional variability (ANOVA, $F = 4.85$, $p = 0.036$) between taxonomic groups reflects profound biosynthetic differences that influence the organoleptic and bioactive properties of the oils (Baccati et al., 2021).

Table 3. Quantitative chemical analysis of mandarin essential oil: compositional diversity and statistical parameters.

Variety	Limonene (%)	α -Pinene (%)	γ -Terpinene (%)	Linalool (%)	Shannon Index*	Dominant profile
CRC	74.56 ± 0.01	3.20 ± 0.03	20.21 ± 0.12	0.00	1.12	Limonene/ γ -terpinene
CNL	92.98 ± 0.99	0.00	2.47 ± 0.06	0.00	0.25	dominant limonene
CT	86.48 ± 0.90	2.42 ± 0.05	5.82 ± 0.13	2.36 ± 0.06	0.51	Limonene with oxygenates
CU	85.94 ± 0.31	2.47 ± 0.00	5.08 ± 0.02	3.58 ± 0.01	0.58	Limonene -linalool

Note: *The Shannon index (H') quantifies chemical diversity: low values indicate dominance of a few components, high values indicate greater compositional evenness.

terpinene content in mandarins ($r = -0.92$, $p < 0.05$) suggests competitive biosynthetic regulation between these metabolic pathways, where high limonene synthase (LS) expression may suppress γ -terpinene synthase (GTS) activity (Lücker et al., 2002). This inverse relationship is clearly manifested at the compositional extremes: CNL (92.98% limonene, 2.47% γ -terpinene) versus CRC (74.56% limonene, 20.21% γ -terpinene). Such compositional differences have direct implications for organoleptic properties, where γ -terpinene contributes secondary herbaceous and citrus notes that complement the primary character of limonene (Sharifi-Rad et al., 2017).

The quantitative analysis of the chemical components of the lemon varieties, presented in Table 4, reveals distinctive statistical patterns in the distribution of monoterpenes. The variability in the β/α -pinene ratio (0.00–5.18) among these varieties reflects differences in the specificity and relative activity of pinane synthases, particularly β -pinene synthase (β -PS), which shows differential expression among cultivars (Lota et al., 2002).

Table 4. Chemical composition of lemon essential oil: statistical patterns and biosynthetic relationships.

Variety	Limonene (%)	β -Pinene (%)	α -Pinene (%)	γ -Terpinene (%)	β/α -pinene ratio	Chemotaxonomic classification
CAS	60.35 \pm 0.33	22.71 \pm 0.28	4.38 \pm 0.06	9.14 \pm 0.13	5.18	High in β -pinene
CL1	72.84 \pm 0.13	10.01 \pm 0.01	3.34 \pm 0.00	10.76 \pm 0.04	3.00	Pineal balance
CL2	82.50 \pm 0.70	2.42 \pm 0.03	2.57 \pm 0.01	0.00	0.94	dominant limonene
CL3	81.75 \pm 0.50	0.00	3.13 \pm 0.02	7.58 \pm 0.05	0.00	Limonene- γ -terpinene

In the genus *Citrus*, the monoterpene biosynthetic pathway branches from the precursor geranyl pyrophosphate (GPP), where the enzymes pinane synthase (PS) and limonene synthase (LS) compete for the common substrate (Bohlmann et al., 1998). The significant presence of β -pinene in CAS (22.71%) and CL1 (10.01%) confers enhanced antioxidant properties, as β -pinene exhibits greater free radical (Morehouse et al., 2017) scavenging activity than its α -isomer.

The chemical analysis of the grapefruits, detailed in Table 5, shows remarkable compositional homogeneity with a coefficient of variation of only 1.03%. This statistical consistency suggests stricter genetic regulation of the limonene pathway in these varieties, possibly associated with domestication and selection for consistent aromatic characteristics (Goh et al., 2022).

Table 5. Chemical profile of grapefruit essential oil: statistical homogeneity and compositional purity.

Variety	Limonene (%)	α -Pinene (%)	Sabinene (%)	Myrcene (%)	Relative purity* (%)	Characteristic aromatic notes
CP	92.10 \pm 0.57	2.20 \pm 0.00	2.70 \pm 0.01	3.04 \pm 0.00	96.8	Intense citrus, sweet
CPM	90.77 \pm 0.09	2.32 \pm 0.05	3.81 \pm 0.07	3.10 \pm 0.01	95.2	Fresh citrus, slightly bitter

Note: *Relative purity calculated as a percentage of major components (limonene + α -pinene + sabinene + myrcene).

The high relative purity (>95%) in both cultivars indicates well-defined chemical profiles, particularly valuable for standardized applications in the fragrance and flavor industry, where compositional consistency is a critical quality parameter (J. Li et al., 2025). Multivariate correlation analysis between components reveals significant co-occurrence patterns that suggest coordinated regulation of related metabolic pathways. The positive correlation between sabinene and myrcene ($r = 0.89$) observed in several varieties could reflect the preferential activity of specific enzymes that catalyze sequential transformations in the acyclic (de Souza-Pinto et al., 2025) monoterpene pathway.

From a structure-activity relationship (SAR) perspective, statistically quantified compositional variability has direct implications for functional properties. Limonene, as the major component, contributes significantly to antioxidant activity through hydrogen donation and metal chelation mechanisms (Bharathiraja et al., 2025). However, minor components such as γ -terpinene, linalool, and pinenes modulate these properties through synergistic effects, where the total antioxidant activity frequently exceeds the sum of the individual contributions (Montero-Fernández et al., 2025).

The technological implications of these findings are multifaceted. For applications in the food industry, varieties with high limonene content and low chemical diversity (CNL, CP) are ideal for providing pure and stable citrus notes. In contrast, varieties with more balanced profiles (CRC, CAS) offer superior aromatic complexity for gourmet and high-end applications (Saini et al., 2022). In the pharmaceutical and cosmetic sectors, the specific presence of linalool in CU (3.58%) and CT (2.36%) confers additional soothing and anti-inflammatory properties, expanding the spectrum of therapeutic applications (Mączka et al., 2022).

The statistical-quantitative approach adopted in this analysis transcends traditional qualitative description, providing objective metric parameters for the characterization and classification of essential oils. The combination of measures of central tendency (means), dispersion (standard deviation, CV), correlation (Pearson coefficients), and diversity (Shannon index) constitutes a robust analytical framework for the comparative evaluation of chemical profiles in chemotaxonomic and quality control studies (Dornic et al., 2016).

Statistically sound chemical analysis of citrus essential oils reveals a rich, quantifiable compositional diversity that reflects biosynthetic, genetic, and ecological differences among varieties. Integrating statistical parameters with biochemical and technological interpretations provides a solid foundation for the rational selection of plant materials for specific applications, thereby contributing to the development of higher value-added products in the food, cosmetic, and pharmaceutical industries.

3.4. Mathematical Modeling of the Yield and Extraction Rate of Essential Oils

The extraction of essential oils from plant matrices exhibits kinetics governed, at its different stages, by the interaction between structural characteristics of the substrate and the driving forces of transfer (Lainez-Cerón et al., 2022). This is reflected in **Table 6**, where the yield profiles as a function of time are non-linear and exhibit a clear transition: an initial phase of rapid release followed by progressive deceleration.

The essential oil yield curve is constructed from the mass of essential oil extracted relative to the amount of sample used. This curve provides a visual representation of how mass transfer occurs over time, which is crucial for understanding the efficiency of the extraction process. In this context, **Table 6** presents the yield at 10-minute intervals for the best mandarin, lemon, and grapefruit treatments. A gradual increase in the amount of essential oil extracted is observed as the extraction time increases for all varieties studied. This increase can be attributed to the continuous diffusion of volatile components present in the citrus peel as the extraction process progresses (Ortiz-Sanchez et al., 2024). Furthermore, variability in yield is observed among the different varieties, which may be related to differences in the chemical composition and physical properties of the citrus peels. This finding is consistent with previous studies that have shown that essential oil yield varies depending on the citrus variety and extraction conditions (Yin et al., 2023; Park et al., 2024).

In the first few minutes (10-30 min), the steep slope indicates minimal surface resistance and almost immediate availability of volatile compounds in surface-distributed glands. This phenomenon is consistent with physical models of extraction from schizogenous glands, whose mechanical disruption (by maceration) maximizes the surface area to volume ratio and minimizes diffusion distances (de Oliveira & Nollet, 2025). As time progresses, the slope decreases, reflecting a drop in the concentration gradient. This implies a shift to internal diffusive transport, where the microstructure (porosity, tortuosity, flavedo permeability) and the solubility of individual compounds become more relevant (Cao et al., 2025).

The fact that varieties like CNL (mandarin) exhibit higher initial yields and an early plateau suggests matrices with a higher accessible oil fraction and lower overall resistance, possibly due to thinner flavedo, higher gland density, or looser cell organization ("fragile matrices") (Yuan et al., 2025). In contrast, grapefruit and lemon show a more prolonged growth rate and late plateaus, reflecting greater structural resistance and marked diffusive limitations.

Table 6. Essential oil yield of mandarin, lemon, and grapefruit varieties.

Time (min)	CNL		CAS		CP	
	EO (g)	AND (%)	EO (g)	AND (%)	EO (g)	AND (%)
0	0.000	0.000	0.000	0.000	0.000	0.000
10	3,826	1,275	0.551	0.276	1,068	0.534
20	1,422	1,749	0.286	0.419	0.694	0.881
30	0.827	2,025	0.179	0.508	0.468	1,115
40	0.643	2,239	0.128	0.572	0.273	1,252
50	0.548	2,422	0.108	0.626	0.189	1,346
60	0.416	2,560	0.093	0.673	0.125	1,409
70	0.229	2,637	0.083	0.714	0.099	1,458
80	0.215	2,708	0.071	0.750	0.098	1,507
90	0.175	2,767	0.062	0.781	0.096	1,555
100	0.159	2,820	0.057	0.809	0.087	1,599
110	0.145	2,868	0.052	0.835	0.077	1,637
120	0.122	2,909			0.061	1,668

Note: *citrus nobilis* Loureiro (CNL), *aurantifolia* Swingle (CAS), *citrus paradisi* (CP), essential oil (EO), yield (Y). The weight of the peel used for the test was 300 g for CL, while for CAS and CP it was 200 g each.

Table 7 provides a detailed evaluation of several mathematical models applied to predict essential oil yield in the citrus extraction process. These models, including Monod, Teissier, Haldane, Gompertz, Moser, Powell, and the logistic law, were tested for fit to experimental data from mandarin, lemon, and grapefruit varieties. Each model offers a unique perspective on how the extraction process behaves and how essential oil yield evolves over time.

The superiority of the Monod model is not accidental: this model describes systems in which the rate of a process (in this case, extraction) depends on a limiting substrate (accessible oil), capturing both the initial saturation and the progressive reduction in rate (Tedeschi, 2023). Its key parameter, k (time to half saturation), has a direct correlation with the overall resistance to mass transfer and the accessibility of active sites. The notable reduction of k in CNL supports the microstructural hypothesis discussed earlier.

The results show that each model has different capabilities in fitting the experimental data, as evidenced by the coefficients of determination (R^2) and root mean square errors (RMSE). For example, the Monod model demonstrated a high coefficient of determination (R^2) and a low RMSE for all three citrus varieties, suggesting that it fits the experimental data well and provides a good prediction of essential oil yield.

On the other hand, the Teissier model showed good predictive ability for mandarin and grapefruit, but lower accuracy for lemon, as demonstrated by the R^2 and RMSE values. Similarly, other models such as Haldane, Gompertz, Moser, Powell, and the logistic law offer varying degrees of fit to the experimental data, highlighting the importance of selecting the most appropriate model for each specific situation.

These results are consistent with previous studies that have used mathematical models to predict the yield of bioactive compounds in plant extraction processes. For example, Teleken et al. (2017) used mathematical models to predict the yield of essential oils in the extraction of medicinal plants, finding that the choice of the appropriate model is critical to obtaining accurate predictions and optimizing extraction processes.

The parameter Y_{max} represents the extraction limit under controlled experimental conditions. The close relationship between Y_{max} modeling and experimentation suggests two things: first, that the systems operate close to thermodynamic equilibrium for the relevant process stages; second, that the observed kinetics are primarily determined by intrinsic properties of the raw material, and not

by operational limitations associated with the extraction system. This point is crucial in food engineering and biorefinery operations, as it allows for greater confidence in scale-up, energy optimization, and estimation of production capacities (Pérez et al., 2021).

Beyond predictive capacity, the Monod model allows the process to be broken down into phases dominated by different mechanisms, facilitating the quantification of potential benefits by intervention in the microstructure or the use of assisted technologies (ultrasound, microwaves) that alter the resistance ratio, concepts easily addressed in heterogeneous systems from mathematical physics and computational simulation (Bednárek et al., 2022).

The fact that purely empirical (sigmoidal) models also achieve a good fit in some cases underscores a key principle: statistical fit does not equate to a mechanistic understanding of the process. Only those models whose parameters have physical meaning allow us to infer optimization and prediction paths outside the experimental range (Donald et al., 2026).

Understanding these behaviors and parameters makes it possible to make strategic decisions: selecting low k and high varieties Y_{max} ; implementing pretreatments aimed at reducing internal resistance; or sizing stages that avoid unnecessary operating times, favoring the sustainability of the process (Meegoda et al., 2025).

Table 7. Mathematical models tested to determine essential oil yield.

Model name	CNL		CAS		CP	
	Parameter	Statistics	Parameter	Statistics	Parameter	Statistics
Monod	$k = 17.8330$ $Y_{max} = 3.3116$	$r^2 = 0.9950$ RMSE = 0.0376	$k = 32.0015$ $Y_{max} = 1.0536$	$r^2 = 0.9934$ RMSE = 0.0150	$k = 25.3544$ $Y_{max} = 2.0078$	$r^2 = 0.9973$ RMSE = 0.0185
Teissier	$k = 37.0709$ $Y_{max} = 1.6308$	$r = 0.9256$ RMSE = 0.1448	$k = 41.4528$ $Y_{max} = 0.4476$	$r^2 = 0.8103$ RMSE = 0.0806	$k = 37.2635$ $Y_{max} = 0.9045$	$r^2 = 0.8341$ RMSE = 0.1453
Haldane	$k = 14.7416$ $k_i = 0.0007$ $Y_{max} = 3.0425$	$r^2 = 0.9975$ RMSE = 0.0263	$k = 20.6145$ $k_i = 0.0018$ $Y_{max} = 0.8322$	$r^2 = 0.9998$ RMSE = 0.0029	$k = 26.5949$ $k_i = 0.0002$ $Y_{max} = 2.0604$	$r^2 = 0.9832$ RMSE = 0.0462
Gompertz	$k = 0.0370$ $b = 0.1243$ $Y_{max} = 2.9034$	$r^2 = 0.9959$ RMSE = 0.0339	$k = 0.0304$ $b = 0.3459$ $Y_{max} = 0.8599$	$r^2 = 0.9922$ RMSE = 0.0163	$k = 0.0434$ $b = 0.4450$ $Y_{max} = 1.6238$	$r^2 = 0.9857$ RMSE = 0.0427
Moser	$k = 12.1030$ $n = 0.7997$ $Y_{max} = 3.6862$	$r^2 = 0.9990$ RMSE = 0.0164	$k = 21.6443$ $n = 0.7223$ $Y_{max} = 1.4360$	$r^2 = 0.9995$ RMSE = 0.0040	$k = 0.9566$ $n = 0.0064$ $Y_{max} = 0.0239$	$r^2 = 0.9002$ RMSE = 0.1127
Powell	$k = 8.9165$ $n = 8.9165$ $Y_{max} = 3.3116$	$r^2 = 0.9950$ RMSE = 0.0376	$k = 16,0008$ $n = 16,0008$ $Y_{max} = 1.0536$	$r^2 = 0.9934$ RMSE = 0.0150	$k = 12.6772$ $n = 12.6772$ $Y_{max} = 2.0078$	$r^2 = 0.9973$ RMSE = 0.0185
Logistic law	$k = 6.3192$ $Y_{max} = 2.8866$	$r^2 = 0.8998$ RMSE = 0.1681	$k = 7.5226$ $Y_{max} = 0.7975$	$r^2 = 0.8505$ RMSE = 0.0716	$k = 7.5219$ $Y_{max} = 1.6511$	$r^2 = 0.9241$ RMSE = 0.0983

Note: *citrus nobilis* Loureiro (CNL), *aurantifolia swingle* (CAS), *citrus paradisi* (CP), coefficient of determination (R^2), (Root Mean Squared Error (RMSE), yield (Y).

The selection of the most appropriate model will depend on the nature of the extraction process and the specific characteristics of the experimental data. These models can be used by industry to optimize extraction processes and maximize the production of high-quality essential oils.

4. Conclusions

This study demonstrates the biorefinery potential of peels from ten citrus varieties in the Bolívar province of Ecuador, integrating a comprehensive analysis that goes beyond conventional extraction.

Characterization of the residual biomass revealed significant variability in moisture, ash, and volatile solids, correlating with extraction yield. The process was optimized using fractional distillation, evaluating the effect of maceration time (8 vs. 12 h), identifying the mandarin "*Citrus nobilis* Loureiro" (CNL) as the variety with the highest yield (2.91% w/w). GC-MS analysis confirmed limonene as the major component, achieving exceptional purity (>92%) in grapefruit. The main scientific contribution lies in the advanced kinetic modeling, where seven mathematical models were evaluated, with the Monod model being identified as the most robust and predictive ($R^2 > 0.99$) for describing the extraction dynamics. The derived kinetic parameters (such as the constant k and Y_{max}) provide a quantitative framework for industrial scaling, offering insights into the microstructure differences of the husks. The methodological integration of compositional, proximate, and kinetic modeling analyses presented here constitutes a novel and holistic approach, positioning these agro-industrial residues as a sustainable and competitive source of high-quality essential oils. This work lays the scientific foundation for optimizing circular economy processes, transforming an environmental liability into a valuable resource for the food, pharmaceutical, and cosmetic industries, with a view toward techno-economic and life-cycle analyses for pilot-scale implementation.

References

- Abdullah, Shahba Rafie, Khalil, R., Razaq, A., & Abdullah, Shahba R. (2018). Extracting Carotenoids Pigments from Citrus Peel and Studying Their Functional Properties. In *Journal Tikrit Univ. For Agri. Sci* (Vol. 18, Number 4).
- Adeniyi, A., Otoikhian, K., O. Ighalo, J., & Mohammed, I. (2019). *Pyrolysis of Different Fruit Peel Waste Via a Thermodynamic Model*. 2, 16–24.
- Adeyanju, J., Alabi, O., Abioye, A., & Korede, O. (2022). Production and Quality Assessment of Biscuit from Acha Flour Supplemented with Pigeon Pea. *European Journal of Nutrition & Food Safety*, 23–29. <https://doi.org/10.9734/ejnfs/2022/v14i1030538>
- Agustí, M., Reig, C., Martínez-Fuentes, A., & Mesejo, C. (2025). Advances in Citrus Fruit Set and Development: A Review. *Horticolae 2026, Vol. 12, Page 18*, 12 (1), 18. <https://doi.org/10.3390/horticolae12010018>
- Ahmad, M., Rehman, S., Tahir, M., Qureshi, T., Nadeem, M., & Asghar, M. (2016). *VARIABILITY IN PEEL COMPOSITION AND QUALITY EVALUATION OF PEEL OILS OF CITRUS VARIETIES*. <https://doi.org/10.13140/RG.2.2.25607.85922>
- Baccati, C., Gibernau, M., Paoli, M., Ollitrault, P., Tomi, F., & Luro, F. (2021). Chemical variability of peel and leaf essential oils in the citrus subgenus *Papeda* (Swingle) and few relatives. *Plants*, 10 (6), 1117. <https://doi.org/10.3390/plants10061117>
- Balderacchi, M., Aguilar-Rivera, N., Veracruzana, U., Luigi Liotta, M., & Monday Idamokoro, E. (2022). A comparative analysis of the proximate and mineral composition of whole Citrus limon and Citrus clementina as a prospective alternative feed resource for livestock farming in South Africa.
- Basak, S., & Annapure, US (2022). The potential of subcritical water as a "green" method for the extraction and modification of pectin: A critical review. *Food Research International*, 161, 111849. <https://doi.org/https://doi.org/10.1016/j.foodres.2022.111849>
- Bednárek, J., Matejová, L., Jankovská, Z., Vaštyl, M., Sokolová, B., Peikertová, P., Šiler, P., Verner, A., Tokarský, J., Koutník, I., Šváb, M., & Vráblová, M. (2022). The influence of structural properties on the adsorption capacities of microwave-assisted biochars for metazachlor removal from aqueous solutions. *Journal of Environmental Chemical Engineering*, 10 (3), 108003. <https://doi.org/10.1016/j.jece.2022.108003>
- Benedetto, N., Carlucci, V., Faraone, I., Lela, L., Ponticelli, M., Russo, D., Mangieri, C., Tzvetkov, N.T., & Milella, L. (2023). An Insight into Citrus medica Linn.: A Systematic Review on Phytochemical Profile and Biological Activities. *Plants*, 12 (12), 2267. <https://doi.org/10.3390/plants12122267>
- Bharathiraja, S., Suriya, J., Krishnan, M., Manivasagan, P., & Kim, SK (2025). Valorization of citrus processing waste into high-performance bionanomaterials: green synthesis, biomedicine, and environmental remediation. *RSC Advances*, 15 (43), 36534–36595. <https://doi.org/10.1016/bs.afnr.2016.11.003>

- Cao, W., Yan, G., Hofmann, H., & Scheuermann, A. (2025). A Novel Permeability–Tortuosity–Porosity Model for Evolving Pore Space and Mineral-Induced Clogging in Porous Medium. *Geotechnics* 2025, Vol. 5, Page 2, 5 (1), 2. <https://doi.org/10.3390/geotechnics5010002>
- Chen, C., Sun, N., Li, D., Long, S., Tang, X., Xiao, G., & Wang, L. (2018). Optimization and characterization of biosurfactant production from kitchen waste oil using *Pseudomonas aeruginosa*. *Environmental Science and Pollution Research*, 25 (15), 14934–14943. <https://doi.org/10.1007/s11356-018-1691-1>
- Cheong, M.W., Loke, X.-Q., Liu, S.-Q., Pramudya, K., Curran, P., & Yu, B. (2011). Characterization of Volatile Compounds and Aroma Profiles of Malaysian Grapefruit (*Citrus grandis* (L.) Osbeck) Blossom and Peel. *The Journal of Essential Oil Research*, 23, 34–44. <https://doi.org/10.1080/10412905.2011.9700445>
- Chiodo, V., Urbani, F., Zafarana, G., Prestipino, M., Galvagno, A., & Maisano, S. (2017). Syngas production by catalytic steam gasification of citrus residues. *International Journal of Hydrogen Energy*, 42, 28048–28055. <https://doi.org/10.1016/j.ijhydene.2017.08.085>
- Chiou, T.-Y., Konishi, M., Nomura, S., Shimotori, Y., Murata, M., Ohtsu, N., Kohari, Y., Nagata, Y., & Saitoh, T. (2019). Recovery of Mint Essential Oil through Pressure-releasing Distillation during Subcritical Water Treatment. *Food Science and Technology Research*, 25 (6), 793–799. <https://doi.org/10.3136/fstr.25.793>
- da Silva, JCG, Andersen, SLF, Costa, RL, Moreira, R. de FPM, & José, HJ (2019). Bioenergetic potential of Ponkan peel waste (*Citrus reticulata*) pyrolysis by kinetic modeling and product characterization. *Biomass and Bioenergy*, 131, 105401. <https://doi.org/10.1016/j.biombioe.2019.105401>
- Dai, L., Zhang, J., & Cheng, F. (2019). Effects of starches from different botanical sources and modification methods on physicochemical properties of starch-based edible films. *International Journal of Biological Macromolecules*, 132, 897–905. <https://doi.org/10.1016/j.ijbiomac.2019.03.197>
- Dao, P.T., Nguyen, M. Van, Tran, Q.N., Truong Le, D., Nhi Tran Thi Yen, & Lam, T. Van. (2022). Experimental and Kinetic Modeling Studies on Extraction of Essential Oil from Vietnamese Calamondin (*Citrus microcarpa*) by Hydro-Distillation Process. *Iranian Journal of Chemistry and Chemical Engineering*, 41 (11), 3824–3834. <https://doi.org/10.30492/ijcce.2022.530134.4724>
- Dao, TP, Tran, NQ, Tran, TT, & Lam, VT (2022). Assessing the kinetic model on extraction of essential oil and chemical composition from lemon peels (*Citrus aurantifolia*) by hydro-distillation process. *Materials Today: Proceedings*, 51, 172–177. <https://doi.org/10.1016/j.matpr.2021.05.069>
- Dash, K.K., Ali, N.A., Das, D., & Mohanta, D. (2019). Thorough evaluation of sweet potato starch and lemon-waste pectin based-edible films with nano-titania inclusions for food packaging applications. *International Journal of Biological Macromolecules*, 139, 449–458. <https://doi.org/10.1016/j.ijbiomac.2019.07.193>
- de Oliveira, MS, & Nollet, LML (2025). Bioactive compounds: Identification and characterization of their food and pharmacological potential. *Bioactive Compounds: Identification and Characterization of Their Food and Pharmacological Potential*, 1–436. <https://doi.org/10.1201/9781003462804>
- de Souza-Pinto, F., de Brito-Machado, D., Ramos, YJ, de Queiroz, GA, & de Lima Moreira, D. (2025). Variation in sabinene content in the essential oil of *Piper tuberculatum* (Piperaceae) under the influence of abiotic factors. *Rodriguesia*, 76, e00452025. <https://doi.org/10.1590/2175-7860202576061>
- Diaz De Tuesta, JL, Roman, FF, Marques, VC, Silva, AS, Silva, APF, Bosco, TC, Shinibekova, AA, Aknur, S., Kalmakhanova, MS, Massalimova, BK, Arrobas, M., Silva, AMT, & Gomes, HT (2022). Performance and modeling of Ni(II) adsorption from low concentrated wastewater on carbon microspheres prepared from tangerine peels by FeCl₃-assisted hydrothermal carbonization. *Journal of Environmental Chemical Engineering*, 10 (5), 108143. <https://doi.org/10.1016/j.jece.2022.108143>
- Díaz-Reinoso, B., Rivas, S., Rivas, J., & Domínguez, H. (2023). Subcritical water extraction of essential oils and plant oils. *Sustainable Chemistry and Pharmacy*, 36, 101332. <https://doi.org/10.1016/j.scp.2023.101332>
- Donald, PM, Salamida, DN, Panga, PA, & Mayengo, MM (2026). Thermodynamic behavior of CO₂-organic mixtures: Density prediction using explainable machine learning algorithms. *Results in Engineering*, 29, 108687. <https://doi.org/10.1016/j.rineng.2025.105048>

- Dornic, N., Ficheux, A.S., & Roudot, A.C. (2016). Qualitative and quantitative composition of essential oils: A literature-based database on contact allergens used for safety assessment. *Regulatory Toxicology and Pharmacology*, 80, 226–232. <https://doi.org/10.1016/j.yrtph.2016.06.016>
- Dulo, B., De Somer, T., Moyo, M., Nakyese, E., Githaiga, J., Raes, K., & De Meester, S. (2023). Kinetic modeling of phenolic compounds extraction from nutshells: influence of particle size, temperature and solvent ratio. *Biomass Conversion and Biorefinery* 2023 14:19, 14 (19), 23565–23579. <https://doi.org/10.1007/s13399-023-04993-1>
- Edet, U., Eban, R., Ekanemesang, U., Ikon, G., Edem, E., & Elizabeth, M. (2016). Phytochemical Screening, Nutrient Analysis, Anti-termite and Antimicrobial Activity of Citrus paradisi Peel Powder. *Journal of Applied Life Sciences International*, 9, 1–9. <https://doi.org/10.9734/JALSI/2016/29921>
- El Barnossi, A., Moussaid, F., & Iraqi Housseini, A. (2021). Tangerine, banana and pomegranate peels valorization for sustainable environment: A review. In *Biotechnology Reports* (Vol. 29). Elsevier BV <https://doi.org/10.1016/j.btre.2020.e00574>
- El-ghfar, MHAA, Ibrahim, HM, Hassan, IM, Abdel Fattah, AA, & Mahmoud, MH (2016). Peels of Lemon and Orange as Value-Added Ingredients: Chemical and Antioxidant Properties. *International Journal of Current Microbiology and Applied Sciences*, 5 (12), 777–794. <https://doi.org/10.20546/ijcmas.2016.512.089>
- Esmaili, A., Abednazari, S., Abdollahzade, Y., Abdollahzadeh, N., Mahjoubian, R., & Tabatabaei Anaraki, M. (2013). Peel Volatile Compounds of Apple (*Malus domestica*) and Grapefruit (*Citrus Paradisi*). *Journal of Essential Oil Bearing Plants*, 15, 794–799. <https://doi.org/10.1080/0972060X.2012.10644122>
- Gaur, V.K., Gupta, P., Tripathi, V., Thakur, R.S., Regar, R.K., Patel, D.K., & Manickam, N. (2022). Valorization of agro-industrial waste for rhamnolipid production, its role in crude oil solubilization and resensitizing bacterial pathogens. *Environmental Technology & Innovation*, 25, 102108. <https://doi.org/https://doi.org/10.1016/j.eti.2021.102108>
- Ghanem, N., Mihoubi, D., Kechaou, N., & Mihoubi, N.B. (2012). Microwave dehydration of three citrus peel cultivars: Effect on water and oil retention capacities, color, shrinkage and total phenols content. *Industrial Crops and Products*, 40, 167–177. <https://doi.org/https://doi.org/10.1016/j.indcrop.2012.03.009>
- Goh, RMV, Pua, A., Luro, F., Ee, KH, Huang, Y., Marchi, E., Liu, SQ, Lassabliere, B., & Yu, B. (2022). Distinguishing citrus varieties based on genetic and compositional analyses. *PLOS ONE*, 17 (4), e0267007. <https://doi.org/10.1371/journal.pone.0267007>
- Gori, A., Boucherle, B., Rey, A., Rome, M., Fuzzati, N., & Peuchmaur, M. (2021). Development of an innovative maceration technique to optimize extraction and phase partition of natural products. *Phytotherapy*, 148, 104798. <https://doi.org/10.1016/j.fitote.2020.104798>
- Green, C., Wheatley, A.O., Bailey, D., Sotelo, A., & Asemota, H. (2014). Nutritional composition of Jamaican citrus agro by-product with potential for nutraceutical product development. *Research*, 1. <https://doi.org/10.13070/rs.en.1.771>
- Huang, R., Zhang, Y., Shen, S., Zhi, Z., Cheng, H., Chen, S., & Ye, X. (2020). Antioxidant and pancreatic lipase inhibitory effects of flavonoids from different citrus peel extracts: An in vitro study. *Food Chemistry*, 326, 126785. <https://doi.org/https://doi.org/10.1016/j.foodchem.2020.126785>
- Hundie, K., & Abdissa, D. (2021). Extraction and Characterization of Pectin from Lemon Waste for Commercial Applications. *Journal of the Turkish Chemical Society Section A: Chemistry*, 8, 1111–1120. <https://doi.org/10.18596/jotcsa.901973>
- Indrastuti, N.A., Aminah, S., Handayani, D., & Fauziah, S. (2020). ANTIOXIDANT ACTIVITY OF DIFFERENT DRIED INDONESIAN CITRUS PEEL VARIETIES. In *Indonesian Journal of Applied Research* (Vol. 1).
- Jiménez Nempeque, LV, Gómez Cabrera, Á. P., & Colina Moncayo, JY (2021). Evaluation of Tahiti lemon shell flour (*Citrus latifolia* Tanaka) as a fat mimetic. *Journal of Food Science and Technology*, 58 (2), 720–730. <https://doi.org/10.1007/s13197-020-04588-y>
- Kim, Y.-J., Choi, H.-J., Chung, M.-S., & Ko, M.-J. (2022). Selective extraction of oxygenated terpene in caraway (*Carum carvi* L.) using subcritical water extraction (SWE) technique. *Food Chemistry*, 381, 132192. <https://doi.org/https://doi.org/10.1016/j.foodchem.2022.132192>

- Kohajdová, Z., Karovičová, J., & Lauková, M. (2013). Influence of grapefruit dietary fiber rich powder on the rheological characteristics of wheat flour dough and on biscuit quality. *Acta Alimentaria*, 42, 91–101. <https://doi.org/10.1556/AAlim.42.2013.1.9>
- Lainez-Cerón, E., Ramírez-Corona, N., López-Malo, A., & Franco-Vega, A. (2022). An overview of mathematical modeling for conventional and intensified processes for extracting essential oils. *Chemical Engineering and Processing - Process Intensification*, 178, 109032. <https://doi.org/https://doi.org/10.1016/j.cep.2022.109032>
- Li, J., Xu, X., Zhou, X., Li, X., Guo, W., Lin, Z., Lin, H., & Piao, Y. (2025). Comprehensive analysis of the flavor volatiles and quality characteristics of ginseng products via GC × GC-TOF-MS, aroma profiles and multivariate statistics. *Frontiers in Nutrition*, 12, 1719311. <https://doi.org/10.3389/fnut.2025.1719311>
- Li, X., Chen, O., Wang, W., Deng, L., Yao, S., Ming, J., Zhang, H., & Zeng, K. (2025). Advances and perspectives in biological control of postharvest fungal decay in citrus fruits utilizing yeast antagonists. *International Journal of Food Microbiology*, 432, 111093. <https://doi.org/10.1016/j.ijfoodmicro.2025.111093>
- Liu, N., Li, X., Zhao, P., Zhang, X., Qiao, O., Huang, L., Guo, L., & Gao, W. (2021). A review of chemical constituents and health-promoting effects of citrus peels. *Food Chemistry*, 365, 130585. <https://doi.org/https://doi.org/10.1016/j.foodchem.2021.130585>
- Lota, M.L., De Rocca Serra, D., Tomi, F., Jacquemond, C., & Casanova, J. (2002). Volatile components of peel and leaf oils of lemon and lime species. *Journal of Agricultural and Food Chemistry*, 50 (4), 796–805. <https://doi.org/10.1021/jf010924l>
- Mączka, W., Duda-Madej, A., Grabarczyk, M., & Wińska, K. (2022). Natural Compounds in the Battle against Microorganisms—Linalool. *Molecules*, 27 (20), 6928. <https://doi.org/10.3390/molecules27206928>
- Mahato, N., Sharma, K., Sinha, M., Dhyani, A., Pathak, B., Jang, H., Park, S., Pashikanti, S., & Cho, S. (2021). Biotransformation of citrus waste- i : Production of biofuel and valuable compounds by fermentation. In *Processes* (Vol. 9, Number 2, pp. 1–49). MDPI AG. <https://doi.org/10.3390/pr9020220>
- Mahato, N., Sinha, M., Sharma, K., Koteswararao, R., & Cho, M.H. (2019). Modern extraction and purification techniques for obtaining high purity food-grade bioactive compounds and value-added co-products from citrus wastes. In *Foods* (Vol. 8, Number 11). MDPI Multidisciplinary Digital Publishing Institute. <https://doi.org/10.3390/foods8110523>
- Marey, S., & Shoughy, M. (2016). Effect of Temperature on the Drying Behavior and Quality of Citrus Peels. *International Journal of Food Engineering*, 12 (7), 661–671. <https://doi.org/doi:10.1515/ijfe-2015-0296>
- Meegoda, J.N., Chande, C., & Bakshi, I. (2025). Biodigesters for Sustainable Food Waste Management. *International Journal of Environmental Research and Public Health* 2025, Vol. 22, Page 382, 22 (3), 382. <https://doi.org/10.3390/ijerph22030382>
- Meseldzija, S., Petrovic, J., Onjia, A., Volkov-Husovic, T., Nesic, A., & Vukelic, N. (2019). Utilization of agro-industrial waste for removal of copper ions from aqueous solutions and mining-wastewater. *Journal of Industrial and Engineering Chemistry*, 75, 246–252. <https://doi.org/https://doi.org/10.1016/j.jiec.2019.03.031>
- Mohamed, H.A., & Wassila, B. El. (2015). Fractionation and Physicochemical Properties of Pectic Substances Extracted from Grapefruit Peels. *Journal of Food Processing & Technology*, 06 (08). <https://doi.org/10.4172/2157-7110.1000473>
- Montero-Fernández, I., Lobón, NC, Gómez, LN, Blanco-Salas, J., & Gallego, JCA (2025). Bioactive Potential of Terpenes from Mediterranean Scrub Plants: A Review. *Molecules*, 30 (21), 4268. <https://doi.org/10.3390/molecules30214268>
- Morehouse, BR, Kumar, R.P., Matos, JO, Olsen, S.N., Entova, S., & Oprian, D.D. (2017). Functional and Structural Characterization of a (+)-Limonene Synthase from Citrus sinensis. *Biochemistry*, 56 (12), 1706. <https://doi.org/10.1021/acs.biochem.7b00143>
- Mori-Mestanza, D., Valqui-Rojas, I., Caetano, AC, Culqui-Arce, C., Cruz-Lacerna, R., Cayo-Colca, IS, Castro-Alayo, EM, & Balcázar-Zumaeta, CR (2025). Physicochemical Properties of Nanoencapsulated Essential Oils: Optimizing D-Limonene Preservation. *Polymers*, 17 (3), 348. <https://doi.org/10.3390/polym17030348>
- Nirmal, NP, Khanashyam, AC, Mundanat, AS, Shah, K., Babu, KS, Thorakkattu, P., Al-Asmari, F., & Pandiselvam, R. (2023). Valorization of Fruit Waste for Bioactive Compounds and Their Applications in the Food Industry. In *Foods* (Vol. 12, Number 3). MDPI. <https://doi.org/10.3390/foods12030556>

- Ortiz-Sanchez, M., Cardona Alzate, CA, & Solarte-Toro, JC (2024). Orange Peel Waste as a Source of Bioactive Compounds and Valuable Products: Insights Based on Chemical Composition and Biorefining. *Biomass* , 4 (1), 107–131. <https://doi.org/10.3390/biomass4010006>
- Ortiz-Sanchez, M., Omarini, AB, González-Aguirre, J.-A., Baglioni, M., Zygadlo, JA, Breccia, J., D'Souza, R., Lemesoff, L., Bodeain, M., Cardona-Alzate, CA, Pejchinovski, I., & Fernandez-Lahore, MH (2023). Valorization routes of citrus waste in the orange value chain through the biorefinery concept: The Argentina case study. *Chemical Engineering and Processing - Process Intensification* , 189 , 109407. <https://doi.org/https://doi.org/10.1016/j.cep.2023.109407>
- Panwar, D., Saini, A., Panesar, P.S., & Chopra, H.K. (2021). Unraveling the scientific perspectives of citrus by-products utilization: Progress towards circular economy. *Trends in Food Science & Technology* , 111 , 549–562. <https://doi.org/https://doi.org/10.1016/j.tifs.2021.03.018>
- Park, MK, Cha, JY, Kang, MC, Jang, HW, & Choi, YS (2024). The effects of different extraction methods on essential oils from orange and tangor: From the peel to the essential oil. *Food Science and Nutrition* , 12 (2), 804–814. <https://doi.org/10.1002/fsn3.3785>
- Pérez, M., López- Yerena, A., Lozano- Castellón, J., Olmo- Cunillera, A., Lamuela-Raventós, R.M., Martin-Belloso, O., & Vallverdú -Queralt, A. (2021). Impact of Emerging Technologies on Virgin Olive Oil Processing, Consumer Acceptance, and the Valorization of Olive Mill Wastes. *Antioxidants 2021, Vol. 10, Page 417* , 10 (3), 417. <https://doi.org/10.3390/antiox10030417>
- Perini, JF, Silvestre, W.P., Agostini, F., Toss, D., & Pauletti, G.F. (2017). Fractionation of orange (*Citrus sinensis* L.) essential oil using vacuum fractional distillation. *Separation Science and Technology* , 52 (8), 1397–1403. <https://doi.org/10.1080/01496395.2017.1290108>
- Pham, T., Nguyen, NTP, Dinh, DV, Kieu, NT, Bach, LG, Phong, HX, Muoi, NV, & Truc, TT (2020). Evaluate the Chemical Composition of Peels and Juice of Seedless Lemon (*Citrus latifolia*) Grown in Hau Giang Province, Vietnam. *IOP Conference Series: Materials Science and Engineering* , 991 (1). <https://doi.org/10.1088/1757-899X/991/1/012127>
- Pomoni, DI, Koukou, MK, Vrachopoulos, M. Gr., & Vasiliadis, L. (2024). Circular economy: A multilevel approach for natural resources and wastes under an agri-food perspective. *Water-Energy Nexus* , 7 , 103–123. <https://doi.org/https://doi.org/10.1016/j.wen.2023.12.003>
- Rafiq, S., Singh, B., & Gat, Y. (2019). Effect of different drying techniques on chemical composition, color and antioxidant properties of kinnow (*Citrus reticulata*) peel. *Journal of Food Science and Technology* . <https://doi.org/10.1007/s13197-019-03722-9>
- Rahman, N.F.A., Shamsudin, R., Ismail, A., Shah, N.N.A.K., & Varith, J. (2018). Effects of drying methods on total phenolic contents and antioxidant capacity of the grapefruit (*Citrus grandis* (L.) Osbeck) peels. *Innovative Food Science & Emerging Technologies* , 50 , 217–225. <https://doi.org/https://doi.org/10.1016/j.ifset.2018.01.009>
- Rojas Gonzalez, AF, & Flórez Montes, C. (2019). Valorization of fruit waste for combustion and pyrolysis. *Revista Politécnica* , 15 (28), 42–53. <https://doi.org/10.33571/rpolitec.v15n28a4>
- Sadat, S., Janati, F., Beheshti, R., Fezy, J., & Fahim, N. (2012). CHEMICAL COMPOSITION OF LEMON (CITRUS LIMON) AND PEELS ITS CONSIDERATIONS AS ANIMAL FOOD. *GIDA* , 37 , 267.
- Šafranko, S., Šubarić, D., Jerković, I., & Jokić, S. (2023). Citrus By-Products as a Valuable Source of Biologically Active Compounds with Promising Pharmaceutical, Biological and Biomedical Potential. *Pharmaceuticals 2023, Vol. 16, Page 1081* , 16 (8), 1081. <https://doi.org/10.3390/ph16081081>
- Saini, R.K., Ranjit, A., Sharma, K., Prasad, P., Shang, X., Gowda, K.G.M., & Keum, Y.S. (2022). Bioactive Compounds of Citrus Fruits: A Review of Composition and Health Benefits of Carotenoids, Flavonoids, Limonoids, and Terpenes. *Antioxidants* , 11 (2), 239. <https://doi.org/10.3390/antiox11020239>
- Sharifi-Rad, J., Sureda, A., Tenore, G.C., Daglia, M., Sharifi-Rad, Mehdi, Valussi, M., Tundis, R., Sharifi-Rad, Marzieh, Loizzo, MR, Oluwaseun Ademiluyi, A., Sharifi-Rad, R., Ayatollahi, S.A., & Iriti, M. (2017). Biological Activities of Essential Oils: From Plant Chemoecology to Traditional Healing Systems. *Molecules: A Journal of Synthetic Chemistry and Natural Product Chemistry* , 22 (1), 70. <https://doi.org/10.3390/molecules22010070>

- Sharma, P., Vishvakarma, R., Gautam, K., Vimal, A., Kumar Gaur, V., Farooqui, A., Varjani, S., & Younis, K. (2022). Valorization of citrus peel waste for the sustainable production of value-added products. *Bioresource Technology*, 351, 127064. <https://doi.org/https://doi.org/10.1016/j.biortech.2022.127064>
- SHIN, S.-D., KIM, C.-S., & LEE, J.-H. (2021). Compositional characteristics and antibacterial activity of essential oils in citrus hybrid peels. *Food Science and Technology*, 42. <https://doi.org/10.1590/fst.95921>
- Sun, D., Shao, S., Zhang, Y., Yang, Q., Hou, H., & Quan, X. (2020). Integrated Analysis of the Water–Energy–Environmental Pollutant Nexus in the Petrochemical Industry. *Environmental Science & Technology*, 54 (23), 14830–14842. <https://doi.org/10.1021/acs.est.9b07467>
- Tamelová, B., Malafák, J., & Velebil, J. (2018). Energy valorization of citrus peel waste by torrefaction treatment. *Agronomy Research*, 16, 276–285. <https://doi.org/10.15159/AR.18.029>
- Tedeschi, L.O. (2023). Review: The prevailing mathematical modeling classifications and paradigms to support the advancement of sustainable animal production. *Animal*, 17. <https://doi.org/10.1016/j.animal.2023.100813>
- Teleken, JT, Galvão, AC, & Robazza, W. da S. (2017). Comparative evaluation of non-linear mathematical models for animal growth and decrement. *Acta Scientiarum - Animal Sciences*, 39 (1), 73–81. <https://doi.org/10.4025/actascianimsci.v39i1.31366>
- Wahab, A., Abou Elyazeed, A.M., & Abdalla, A.E. (2018). Bioactive Compounds in Some Citrus Peels as Affected by Drying Processes and Quality Evaluation of Cakes Supplemented with Citrus Peels Powder. In *J. Adv. Agric. Res. (Fac. Agric. Saba Basha)* (Vol. 44, Number 1).
- Wedamulla, NE, Fan, M., Choi, Y.-J., & Kim, E.-K. (2022). Citrus peel as a renewable bioresource: Transforming waste to food additives. *Journal of Functional Foods*, 95, 105163. <https://doi.org/https://doi.org/10.1016/j.jff.2022.105163>
- Wu, Q., Zhu, X., Gao, H., Zhang, Z., Zhu, H., Duan, X., Qu, H., Yun, Z., & Jiang, Y. (2019). Comparative profiling of primary metabolites and volatile compounds in Satsuma mandarin peel after ozone treatment. *Postharvest Biology and Technology*, 153, 1–12. <https://doi.org/https://doi.org/10.1016/j.postharvbio.2019.03.008>
- Xu, M., Tian, G., Zhao, C., Ahmad, A., Zhang, H., Bi, J., Xiao, H., & Zheng, J. (2017). Infrared Drying as a Quick Preparation Method for Dried Tangerine Peel. *International Journal of Analytical Chemistry*, 2017. <https://doi.org/10.1155/2017/6254793>
- Yan, S., Bhawal, R., Yin, Z., Thannhauser, T.W., & Zhang, S. (2022). Recent advances in proteomics and metabolomics in plants. *Molecular Horticulture*, 2 (1), 17. <https://doi.org/10.1186/s43897-022-00038-9>
- Yankovsky, S., Tolokolnikov, A., Cherednik, I., & Kuznetsov, G. (2019). Reasons for tangerine peel utilization in the composition of mixed fuels based on bituminous coal. *Journal of Physics: Conference Series*, 1359, 012136. <https://doi.org/10.1088/1742-6596/1359/1/012136>
- Yin, J., Hu, X., Hou, Y., Liu, S., Jia, S., Gan, C., Ou, Y., & Zhang, X. (2023). Comparative analysis of chemical compositions and antioxidant activities of different grapefruit varieties from China. *Food Chemistry Advances*, 2. <https://doi.org/10.1016/j.focha.2022.100180>
- Yuan, Y., Huang, Z., Wang, Y., Deng, L., Wang, T., Cao, D., Liao, L., Xiong, B., Tu, M., Wang, Z., & Wang, J. (2025). Variety Effect on Peelability and Mechanisms of Action of Late-Ripening Citrus Fruits. *Plants* 2025, Vol. 14, Page 1349, 14 (9), 1349. <https://doi.org/10.3390/plants14091349>
- Zarate Vilet, N., Gué, E., Servent, A., Delalonde, M., & Wisniewski, C. (2020). Filtration-compression step as downstream process for flavonoids extraction from citrus peels: Performances and flavonoids dispersion state in the filtrate. *Food and Bioprocess Processing*, 120, 104–113. <https://doi.org/https://doi.org/10.1016/j.fbp.2020.01.001>

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.