CarakaTani
Journal of Sustainable Agriculture
ISSN 2613-9456 (Print) 2599-2570 (Online)

Caraka Tani: Journal of Sustainable Agriculture, 38(1), 176-192, 2023
URL: https://jurnal.uns.ac.id/carakatani/article/view/67769
DOI: http://dx.doi.org/10.20961/carakatani.v38i1.67769

Comparison of Different Techno-Functional Properties of Raw Lemon Pomace and Lemon Pomace Powder, and Development of Nutritional Biscuits by Incorporation of Lemon Pomace Powder

Ashiq Hussain[1,3*], Tusneem Kauser[1], Jawed Aslam[1], Muhammad Yousaf Quddoos[1], Atif Ali[2], Samina Kauser[1], Khurram Kabir[3], Ayesha Rafique[1], Saima Noreen[1], Khansa Iftikhar[1], Tahira Siddique[3] and Faiza Iftikhar Gorsi[1]

[1]Institute of Food Science and Nutrition, University of Sargodha, Sargodha, Pakistan;
[2]Institute of Food and Nutritional Sciences, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Rawalpindi, Pakistan; [3]Punjab Food Authority, Punjab, Pakistan

[*]*Corresponding author:* ashiqft@gmail.com

Abstract

Lemon is one among the fruits of a highly respectable class known as citrus, well known for its nutritious juice and beverage products, rich with a range of micro and macro elements, and functional bioactives. After extraction of juice, the pomace left has great potential as a sustainable agricultural processing by-product, due to its vast application in the food, feed and pharma industries. Lemon pomace powder was prepared from the by-product obtained after the extraction of juice from the lemon. Dried lemon pomace powder contained fiber (60.12 g 100 g^{-1}), moisture (10.67 g 100 g^{-1}), protein (4.89 g 100 g^{-1}), fat (2.17 g 100 g^{-1}), sugar (4.81 g 100 g^{-1}) and ash (3.21 g 100 g^{-1}), indicating higher amounts of ash, fat and fiber contents than wheat flour. The water-holding and oil-holding capacities of lemon pomace powder were noticed 5.9 and 3.2 g, respectively. Lightness (L^*) and yellowness (b^*) of powder were decreased while redness (a^*) was increased in powder as compared to raw pomace. Water activity was decreased, while dry matter and pH of pomace powder were significantly increased as compared to raw pomace. Microbiological analyses revealed lower mold, yeast and total viable counts in lemon pomace powder as compared to raw lemon pomace. Dried lemon pomace powder was replaced with wheat flour at concentrations of 0%, 5%, 10% and 15% in biscuits. The biscuits were evaluated for chemical and sensory properties. Data revealed that the incorporation of lemon pomace powder improved the chemical and sensory properties of biscuits significantly. Highly acceptable biscuits with good sensory properties were obtained by incorporating 10% lemon pomace powder, with the potential use of promoting health.

Keywords: biscuits; dietary fiber; lemon pomace powder; microbiological counts; sensory evaluation

Cite this as: Hussain, A., Kauser, T., Aslam, J., Quddoos, M. Y., Ali, A., Kauser, S., Kabir, K., Rafique, A., Noreen, S., Iftikhar, K., Siddique, T., & Gorsi, F. I. (2023). Comparison of Different Techno-Functional Properties of Raw Lemon Pomace and Lemon Pomace Powder, and Development of Nutritional Biscuits by Incorporation of Lemon Pomace Powder. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(1), 176-192. doi: http://dx.doi.org/10.20961/carakatani.v38i1.67769

INTRODUCTION

Processing industries of food from agricultural crops are producing large quantities of waste biomass in the form of peels, seeds, leaves and pomaces. Efficient utilization of these waste by-products, if carried out with innovative and novel technologies, could not only proven the benefits for mankind but also for the protection of the environment. Functional ingredients, like micro

[*] *Received for publication November 26, 2022*
Accepted after corrections March 6, 2023

and macronutrients, dietary fiber, carotenoids and phenolics, have been reported extensively in agricultural wastes. Incorporating these waste materials into different food products in processed powders, extracts, and isolated bio-actives can produce nutritional and healthy food products (Hussain et al., 2022). Consumption of fresh and processed fruits produces waste by-products, and handling these waste streams has always been a great concern for food processors. Recent studies have revealed that no part of the fruit can be considered waste due to the presence of biologically active components (Hussain et al., 2021). Citrus processing industries are focused on the production of juice, but at the same time huge amounts of waste in the form of pomace, when left untreated, can cause environmental and health risks. Citrus fruit waste valorization can prove an important step toward environmental sustainability (Suri et al., 2021).

Citrus fruits, due to their capacity of health promoting through provision of necessary nutrients, have been listed in the fruits of global economic importance. Citrus fruits have been recognized as free of sodium, cholesterol and sugars. It has been reported that dietary fiber, vitamin C, thiamine, niacin, folic acid, potassium, calcium, phosphorus, magnesium and copper found abundantly in citrus fruits are responsible for lowering the risks of heart diseases, respiratory diseases, diet-related diseases, cancer as well as novel Covid-19 (Bellavite and Donzelli, 2020). Lemon is included in citrus fruits, belonging to the family *Rutaceae*, and is considered the third most important species after orange and mandarin, with a strong economic and commercial value. Of the total production of citrus in the world, about 34% is being utilized by the juice production industry, which results in the production of a large quantity of waste biomass in the form of peel, seeds and pomace. Lemon peel represents the main part of lemon juice by-products and it counts for approximately 50% to 65% of the total fruit weight (Papoutsis et al., 2016). Citrus fruits have been reported to be grown in more than 140 countries of the world; citrus production and trade have continuously increased in recent decades and about one-third of produced fruit worldwide is used for processing. Production of citrus fruits in the world in the calendar year of 2020 has been recorded as 158.49 million tons in an area of 1.07 ha (FAO, 2022).

The pomace of citrus fruits, which contains peel as major portion, has been proposed as a valuable source of dietary fiber and incorporation of this pomace in cereal-based food products will lead to the production of high-fiber food products, which will pose health-promoting effects on consumers (Quiles et al., 2018). Accumulation of these waste residues is an environmental problem, if not handled properly. These by-products are rich sources of dietary fibers, which have beneficial effects on human health. Recommended daily intake of fiber is about 38 g for men and 25 g for women (Trumbo et al., 2002). Consumption of dietary fiber plays an important role in the prevention of various illnesses, such as constipation, hemorrhoids and hypercholesterolemia. Dietary fibers are not only desirable for their nutritional properties but also for their functional and technological properties (Thebaudin et al., 1997). Fruit fibers have been listed as good quality fibers due to their high total and soluble fiber contents, good functional properties (water and oil holding capacities), good colonic ferment ability, and low caloric content (Larrauri, 1999). Moreover, fiber from citrus fruit has better quality than other sources of dietary fiber, due to the presence of associated bioactive compounds (flavonoids and vitamin C) with antioxidant properties, which may exert higher health-promoting effects than the dietary fiber itself (Jiang et al., 2022). Lemon possesses the highest antioxidant potential among citrus fruits and fiber from lemon pomace is the most suitable fiber for the dietary prevention of cardiovascular and other diseases (Gorinstein et al., 2001).

Biscuits are widely consumed as snacks or supplements to other foods for every age of the population because of their ready-to-eat nature, varied shapes, flavors, textures and prolonged shelf life. The production and consumption of biscuits all over the world are increasing day by day due to their potential as food enhancers (Al-Janabi and Yasen, 2022). Strategies have been implemented to alter and modify both functional and nutritional behaviors of biscuits through the incorporation of powders from fruit and vegetable by-products, to treat chronic nutritional-related diseases. Different enrichment options for biscuits include vitamin mixtures, minerals, nutrient rich complimentary ingredients, and fruits and vegetables parts flours. Capability of fortification and high consumer acceptance make biscuits a formulating food with a desired nutritional and functional role for infants, children, the elderly, and patients with special needs like obesity and diabetes (Singh and Kumar, 2017).

The public's expectations are very high from food producers in terms of healthy and nutritious food products, which can play both functional and medicinal roles in the body, and most economic and extraordinary sources of functional ingredients are by-products of fruit and vegetable waste (Hussain et al., 2022). High dietary fiber powder may be used for the enrichment of usually consumed foods for the production of dietary fiber tablets (Fernandez-Gines et al., 2003). In order to take advantage of the dietary and functional properties of fiber, a wide range of high-dietary fiber-formulated foods have been developed and marketed for health-conscious consumers (Tudorica et al., 2002). Jurasova et al. (2011) incorporated lemon and orange by-product powder in wheat flour biscuits. Srivastava et al. (2015) prepared nutritional biscuits by incorporating lemon peel powder in wheat flour at different proportions. Functionalized biscuits were developed by Imeneo et al. (2021), by using citrus pomace powder in white flour. Roy et al. (2021) recommended the incorporation of lemon peel powder for the development of functional biscuits. Orange peel powder-incorporated nutritional biscuits were prepared by Al-Janabi and Yasen (2022). Abdel-Naeem et al. (2022) incorporated lemon, orange, grapefruit and banana peel powders for the development of chicken patties.

Production of new functional foods with acceptable chemical and organoleptic characteristics through the incorporation of fruit and vegetable by-product wastes has been the focus of food producers in recent years and this would prove the key strategy towards implementing a healthy and economic society. In this context, citrus fruits with record production, processing, and consumption, produce huge waste by-products, and the implementation of novel technologies to recover functional ingredients and their addition to add value to the food products could be proven a good strategy towards sustainable economy (Wang et al., 2015). Techno-functional properties of lemon peels and pomace suggest many potential applications in the development of foods reduced in calories and rich in dietary fiber containing a high amount of associated bioactive compounds, such as phenols. The technological properties of dietary fibers of citrus peels are of great interest to food manufacturers such as dietetic drinks, breakfast cereals, dairy products, pastry and bakery products, candy and chocolate factories (Ghanem et al., 2012).

The possibility of successful by-products, including citrus by-products, in the food industry, would help in enhancing the economic development of citrus producers and processors. Competition in the market and the recent demand for healthy food products with low calories and high dietary fiber have inspired us to utilize lemon pomace powder for the production of nutritional biscuits. The aim of the present study was to investigate raw lemon pomace and lemon pomace powder for functional, technological, and microbiological properties and to study the effect of lemon pomace powder incorporation at different levels on the physicochemical and organoleptic properties of wheat biscuits.

MATERIALS AND METHOD

Collection of research materials

Fresh lemons, fully mature and ripened with the average size of 6 cm and oval shape, were procured from local fruit market of Sargodha District, Punjab Province, Pakistan. Other ingredients (straight-grade white flour, sugar, butter and eggs) for the preparation of biscuits were purchased from Abu Junaid cash and carry super store located in Sargodha, Pakistan. Reagents and chemicals for analyses accessed were of Sigma Aldrich (Germany). The same trade reagents were utilized for each trial to avoid any variation in results.

Preparation of lemon pomace powder

Lemon pomace powder was obtained from by-products that remained after extraction of lemon juice from fresh lemons, by following the procedure described by Fernandez-Lopez et al. (2004), with some modifications. Lemons were pressed using a helical press (lemon juice squeezer) to remove liquid juice from the pomace, prior to drying. Drying was carried out in a hot air-based oven (BIOBASE HAS-T105 China), at 60 ^{o}C for 24 hours till the constant weight was achieved, to improve lemon pomace shelf life without the addition of any chemical. Dried pomace was ground by a common spice grinder (NIMA NM-8300 Japan) and sieved with 80 mesh size to obtain fine quality powder for further analyses and incorporation in biscuits development. A graphical flow diagram describing the different steps of preparation of lemon pomace powder has been presented in Figure 1.

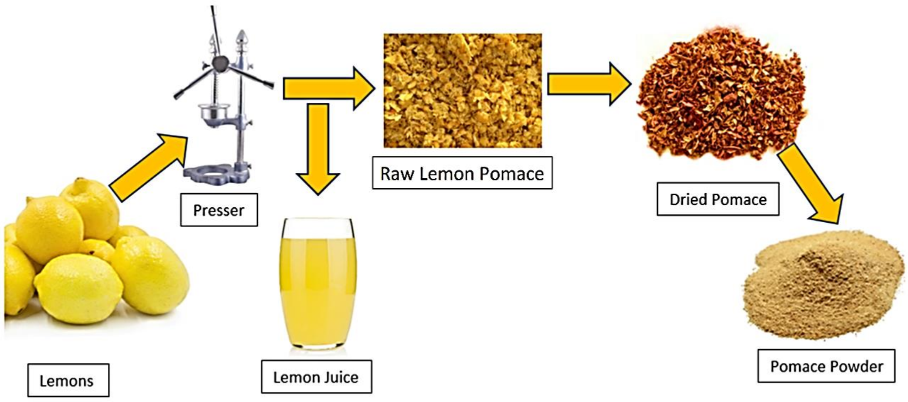


Figure 1. Flow diagram describing the different steps of preparation of lemon pomace powder

Physicochemical and analytical analyses of lemon pomace powder

Proximate composition

Lemon pomace powder, wheat flour, and developed biscuits were analyzed to determine the percentage of moisture (Method No. 44-15A), protein (Method No. 46-12), fat (Method No. 30-10), fiber (Method No. 32-10) and ash (Method No. 8-01) contents according to AACC (2000).

Color parameters

Lemon pomace powder and raw lemon pomace were analyzed with color meter (Minolta CR-300, USA) to determine lightness (*L**), redness (*a**) and yellowness (*b**) color values. Color values were measured based on the method described by Rocha and Morais (2003).

Water and oil holding capacity

Water and oil holding capacity of lemon pomace powder was determined by following the guidelines described by Al-Janabi and Yasen (2022) with required necessary modifications. Lemon pomace powder was taken 0.1 g in a 15 ml test tube and 10 ml distilled water was added to moisten the sample. Mixture was well stirred for 5 minutes and was rested for 30 minutes at room temperature. Then, this test tube was placed in centrifuge at 2000 rpm for 10 minutes, and after that, the supernatant was separated from the tube and the remaining residue was weighed before and after drying to calculate the water holding capacity, which was expressed as the number of grams of water held by 1 g of sample. Equation 1 was used to obtain water holding capacity.

For determination of oil holding capacity, lemon pomace powder was taken 100 mg in a 15 ml test tube and 10 ml corn oil was added in it. The mixture was well stirred and placed in a centrifuge (Hettich Zentrifugen, ROTINA 380R, Germany) for 25 minutes at 1600 rpm. The upper phase was removed and the centrifuge tube was drained for 30 minutes on filter paper. Oil holding capacity was expressed as the number of grams of oil retained by 1 g of lemon pomace powder. Oil holding capacity was determined by using Equation 2.

Dry matter, water activity and pH

Dry matter in raw lemon pomace and lemon pomace powder was determined by adopting method number 934-01, whereas method number 978-18 of AOAC (1995) was used to determine the water activity of lemon pomace powder and raw lemon pomace. For the determination of pH of both raw lemon pomace and lemon pomace powder, aqueous solutions were prepared using 20 g of each sample in 50 ml double distilled water and filtration was performed before pH measurement. The electrode tip of digital pH meter (PH-2606 LOHAND China) was rinsed in deionized water and then in the sample solution by waiting until the reading became steady, which was recorded. The meter calibration was also periodically checked during measurements.

$$\text{Water holding capacity} = \frac{\text{Weight of wet residue (g) - Weight of dry residue (g)}}{\text{Weight of dry residue (g)}} \quad (1)$$

$$\text{Oil holding capacity} = \frac{\text{Weight of content of tube after draining (g) - Weight of dried powder (g)}}{\text{Weight of dried powder (g)}} \quad (2)$$

Microbiological analysis

Lemon pomace powder and raw lemon pomace were analyzed for the number of total viable cells, enterobacteria and yeasts, and mold count as described by Lario et al. (2004) with necessary changes. Briefly describing, serial dilutions of raw lemon pomace and lemon pomace powder were prepared in 0.1% sterile peptone water. For the determination of total viable counts, diluted samples were plated in 3M petri film plates and incubation was done at 37 ^{o}C for 48 hours. Similarly, enterobacteria count was done by plating the diluted samples on 3M petri film and incubating at 37 ^{o}C for 48 hours, while for yeasts and molds count similar procedure was done but the incubation duration was increased to 5 days at 25 ^{o}C for proper growth of microorganisms.

Preparation of biscuits

The biscuits were prepared by following the procedure adopted by Hussain et al. (2022) with some modifications. Briefly explaining, ingredients were weighed and mixed to develop batter, which was sheeted and with the help of molds, biscuits were shaped and placed on stainless steel trays. Baking was carried out in a baking oven at 180 ^{o}C for 20 minutes. Preparation of biscuits was carried out using wheat flour replaced separately with different levels of lemon pomace powder as presented in Table 1. Prepared biscuits were packed in polythene bags and kept on a laboratory shelf at ambient conditions for further analyses. A graphical flow diagram of the preparation of lemon pomace-incorporated biscuits has been presented in Appendix 1.

Table 1. Proportions of wheat flour and lemon pomace powder for the development of biscuits

Treatments	Wheat flour (%)	Lemon pomace powder (%)
T_0	100	0
T_1	95	5
T_2	90	10
T_3	85	15

Sensory evaluation of developed biscuits

Sensory evaluation of the developed products incorporated with lemon pomace powder was done by using nine-point hedonic rating scale as described by Tsikritzi et al. (2014). A panel of 20 experts with an average age of 45 of both genders were provided sheets with scores from 1 to 9, with 1 for strongly dislike and 9 for strongly like. Sample biscuits with specific codes were provided to the experts using distilled water bottles for rinsing and neutralizing the mouth after each test. The obtained data were collected, calculated and analyzed.

Statistical analyses of the data

All analyses were performed in triplicate to get triplicate determinations and results were expressed as means ± standard deviations. The statistical analysis was done using one-way ANOVA. Duncan's multiple-range test was used to differentiate between the mean values (Steel et al., 1997).

RESULTS AND DISCUSSION

Proximate composition analyses of lemon pomace powder and wheat flour

Proximate compositions of dried lemon pomace powder and wheat flour have been presented in Table 2. It can be seen that lemon pomace powder contained significantly higher values of fiber, ash, fat and sugar contents than wheat flour. The key point behind replacing wheat flour with lemon pomace powder was exaggerated amount of fiber (60.12±1.29) in lemon pomace powder.

The obtained results have close resemblance with the findings of Haider et al. (2016) related to chemical composition of wheat flour. Before incorporating pumpkin peel powder in wheat flour for the development of nutritional biscuits, Hussain et al. (2022) made a comparison of pumpkin peel powder, and the proximate composition of wheat flour and the results were much similar to the present study revealing that fruits and vegetable peels contain greater amounts of ash, fiber, and protein as compared to wheat flour. Abdel-Naeem et al. (2022) provided similar results when they analyzed the proximate composition of different citrus fruit peel powders, including lemon, orange, grapefruit and banana, and developed chicken patties by incorporating these powders.

Ojha and Thapa (2017) dried mandarin peel powder for incorporation in wheat flour to develop nutritional biscuits. The comparison between mandarin peel powder and wheat flour showed that higher amounts of fiber, ash and fat were found in mandarin peel powder than in wheat flour, whereas moisture, protein and sugar contents were found lower in mandarin peel powder than in wheat flour. They also reported that mandarin peel powder has appreciable

Table 2. Proximate composition of lemon pomace powder and wheat flour

	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Sugar (%)	Fiber (%)
Lemon pomace powder	10.66±0.39[b]	4.89±0.18[b]	2.17±0.39[a]	3.21±0.41[a]	4.81±0.23[a]	60.12±1.29[a]
Wheat flour	13.25±0.03[a]	9.96±0.03[a]	0.90±0.02[b]	1.12±0.02[b]	0.32±0.01[b]	0.92±0.01[b]

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p < 0.05$)

amounts of polyphenols, carotenoids and ascorbic acid. Jurasova et al. (2011) dried orange and lemon pomace powders to obtain powders and chemical analyses of these powders revealed results supporting the findings of present research as they characterized lemon and orange pomace powders with 56.5% and 63.4% respectively, crude fiber content. Further, contents of moisture (12.3%), ash (5.0%), fat (5.1%) and protein (6.4%) were recognized in lemon pomace powder. Roy et al. (2021) compared the physicochemical properties of blanched and unblanched lemon peel powders dried at different temperatures and the findings were not much different from this study.

Water and oil holding capacities of lemon pomace powder

Data presented in Figure 2 express the water and oil holding capacities of dried lemon pomace powder, from where it can be explained that lemon pomace powder is capable of holding more amount of water than oil and this phenomenon will help to improve the quality of developed food products by positively affecting the technological features of processes. Water holding capacity is explained as the largest amount of water that 1 g of sample can absorb and retain under low sedimentation velocity (AACC, 2000). The observed water holding capacity was similar to the water holding capacity of dried raw lemon fiber reported by Lario et al. (2004). Results supporting this research work have also been found in the findings of Robertson et al. (2000) during the studies of hydration properties of dietary fibers and resistant starches. High water holding capacity of lemon pomace powder suggests that it can be used as a functional ingredient to reduce syneresis, modify texture and viscosity, and reduce the calories of food. Soluble dietary fiber present significantly high in lemon pomace powder had been recognized as the key factor behind increased water holding capacity. The hydration properties of dietary fiber refer to its ability to retain water within its matrix. Fiber with strong hydration properties could increase stool weight by potentially slowing the rate of water absorption from the intestine, as high-water retention in stool makes it easy to pass out (Johnson, 2012). The water holding capacity of lemon peel powder, dried by different techniques, was calculated between 5.31 to 5.75 g g^{-1}, in the findings of the study by Tekgul and Baysal (2018), showing close resemblance with researchers' findings.

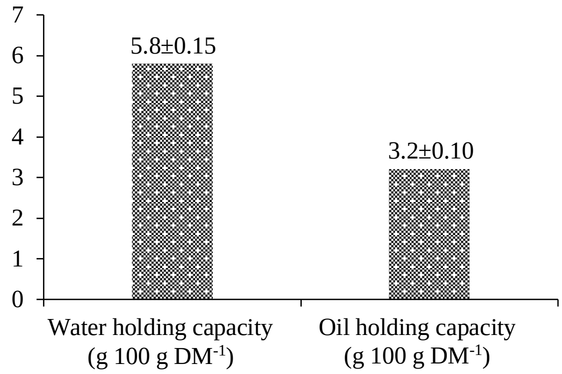


Figure 2. Water and oil holding capacities of dried lemon pomace powder

Water holding capacity of flour depends upon processing of fibers as well as physical and chemical structure of fiber. If the soluble dietary fiber contents in flour are higher, the water holding capacity of the flour will be greater, so citrus fibers possess high water holding capacity due to high soluble dietary fiber contents. Grinding lemon pomace increases fiber density by breaking pores and disturbs the physical structure of fibers. A decrease in fiber particle size causes a reduction in the water-holding capacity but does not affect the oil-holding capacity of lemon pomace fiber (Lario et al., 2004). Chen et al. (1988) reported that lemon and apple fiber have high water-holding capacities and therefore improve the physical characteristics of cakes, bread, and similar cereal products. Jurasova et al. (2011) prepared dietary fiber formulations of lemon and orange by-products and studied their functional properties providing supportive results regarding the water and oil-holding capacities of lemon and orange fiber preparations. Results not much different from researchers were found when water and oil-binding capacities of orange peel powder were determined by Al-Janabi and Yasen (2022) before incorporation in wheat flour for the development of nutritional biscuits.

In a study, decrease in oil holding capacity was found promoted due to the dehydration process of lemon pomace powder as compared to fresh samples. The low contents of fat in lemon pomace powder might be the reason behind the low oil-holding capacity of this powder. Hydrophobic interactions between added oil and already present oil in powders decide the oil-holding capacity of the powder (Ghanem et al., 2012). Garau et al. (2006) determined the oil-holding capacities of air-dried orange peels and provided values slightly higher than our results. This might be due to the reason that a long time and high temperature might have destroyed some of the phenol components, which have the ability to bind and retain fat molecules.

Color parameters of raw lemon pomace and lemon pomace powder

Color parameters of raw lemon pomace and lemon pomace powder have been listed in Table 3, presenting a significant decrease in *L** and *b** significant increase in *a** of lemon pomace powder. Brownish color of lemon pomace powder was due to Maillard reaction and this brown color can be defined as yellow color with low lightness.

Reduction in *L** and increase in *a** might have been occurred due to Maillard reaction compounds, which were produced due to heating during drying process and resulted in extensive browning of developed lemon pomace powder. A decrease in *b** value of lemon pomace powder might be due to the structure of fibers present in lemon pomace, as fiber structures affect the *b** value significantly. The findings of this research work were nearest to the values provided by Lario et al. (2004). In the investigations made by Imeneo et al. (2021) on lemon peels and their extracts relatively lesser values of *L** as 42.33 and *b** as 7.12 were reported for lemon peel extracts, which might be due to the absence of some coloring compounds in the peel extracts. Supportive data were also observed in the research findings of Abdel-Naeem et al. (2022). In the observations of Lagana et al. (2022), values of *L**, *b** and *a** of citrus pomace powder were found 60.18, 22.15 and 7.62, respectively, which were very close to the findings of the current study.

Tekgul and Baysal (2018) made the comparison of quality characteristics of fresh lemon and lemon peel powders dried by application of different techniques and findings for color values revealed a significant difference between fresh lemon and dried lemon peel powder parameters. *L** of lemon peel powder was decreased as compared to fresh lemon, whereas *b** was also decreased but at the same time, *a** was increased, which might be due to the concentration of carotenoid pigments in the dried lemon peel powder. Similar results have also been found in the findings of Hussain et al. (2022) when they dried pumpkin peel by hot air technique and observed a decrease in *L** and *b** of the peel powder. The decomposition of the chlorophyll and carotenoid pigments or nonenzymatic browning reactions might be the reasons for the color variations of fresh and dried peel powders. Different drying techniques provided also different values, which was also dependent on decomposition of the pigments (Guine and Barroca, 2012).

Ghanem et al. (2012) observed significant variation in colorimetric parameters of dried and fresh lemon peels. The decrease in *b** value might be linked with destruction of carotenoids and flavonoids, the agents responsible for yellow to orange color of lemon peels. Further it has been investigated that microwave and hot air-drying results adversely affects the drying process by variations in colors.

Dry matter, water activity and pH of raw lemon pomace and lemon pomace powder

Findings presented in Table 4 elaborate the dry matter, water activity, and pH of raw lemon pomace and lemon pomace powder. Dry matter in lemon pomace powder was significantly increased due to the removal of moisture contents, which were present in higher amounts in raw lemon pomace due to which its dry matter contents were found low. Similarly, the water

Table 3. Color parameters of raw lemon pomace and lemon pomace powder

Treatment	*L**	*a**	*b**
Raw lemon pomace	70.12 ± 0.02^a	-2.30 ± 0.04^b	30.87 ± 0.04^a
Lemon pomace powder	60.36 ± 0.03^b	3.96 ± 0.02^a	24.18 ± 0.03^b

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p < 0.05$)

Table 4. Dry matter, water activity and pH of raw lemon pomace and lemon pomace powder

Treatment	Dry matter (%)	Water activity	pH
Raw lemon pomace	16.84±0.02[b]	0.95±0.02[a]	3.99±0.01[b]
Lemon pomace powder	90.16±0.03[a]	0.19±0.01[b]	4.72±0.01[a]

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p < 0.05$)

activity of raw lemon pomace powder was greater in raw lemon pomace, which was significantly reduced in lemon pomace powder due to drying and this decreased water activity will improve the preservation of lemon pomace powder with a low microbial count. Similar results were present in the studies of Lario et al. (2004), where same parameters were investigated in lemon pomace treated under different conditions. Water activity below 0.6 is considered microbiologically stable and lemon peel powder due to lesser water activity is a good source of nutrients for different formulations in development of juices (Bakshi and Ananthanarayan, 2022). Sankalpa et al. (2017) studied the effect of different drying and grinding techniques on water activity and pH of the orange peel powder and results similar to this study were present as water activity was observed in the range of 0.35 to 0.44 for different methods, whereas results for pH were slightly different for orange peel powder as pH was recorded between 5.89 to 6.26, which might be due to the lesser acidity level of orange as compared to lemon.

Imeneo et al. (2021) investigated lemon peel extracts before the development of functionalized biscuits and reported 3.93 pH of lemon peel extract. Studies of Tekgul and Baysal (2018) provided much similar results supporting the findings of present study, for water activity and pH, during the study of the effect of different drying techniques on the physicochemical and nutritional properties of lemon peel powder. In their investigations, fresh lemon water activity was found 0.98, whereas the water activity of lemon peel powder was calculated as 0.4, and no significant difference in the water activity of lemon peel powder was observed by different drying techniques. Similarly, the pH of fresh lemon was found 4.74, which was increased to 5.62 in microwave-dried lemon peel powder. The lower pH of fresh lemon and increased lemon peel and pomace powder might be due to the loss of volatile acids and ascorbic acid due to drying (Tekgul and Baysal, 2018). Values of water activity and pH of citrus pomace powder were slightly higher in the findings of Lagana et al. (2022), which might be due to the greater moisture contents in citrus pomace powder calculated as compared to the findings of current lemon pomace study.

Microbiological analysis of raw lemon pomace and lemon pomace powder

From the data expressed in Table 5, it was clear that a significant decrease in microbial count of dried lemon pomace powder was there as compared to raw lemon pomace. This decrease in microbial count of lemon pomace powder was obviously due to drying as expected. Similar findings have been observed in the research work of Fernandez et al. (1993), where lower count of mesophilic bacteria was recorded in citrus fiber powder obtained in experimental conditions in the laboratory. Results of our study were also in close resemblance with the findings of Larrauri (1994). Supportive results have also been found in the work published by Fernandez et al. (1995). Microbiological analysis of dough incorporated with lemon peel extracts and the lower bacterial count was noted, which might be due to the antimicrobial potential of lemon peel components (Imeneo et al., 2021). Essential oils, polysaccharides, flavonoids, limonoids, tetrazine and coumarin have been found as prominent compounds present in lemon peels and pomace, which have antimicrobial potential (Jiang et al., 2022).

Table 5. Microbiological analysis of raw lemon pomace and lemon pomace powder

Treatment	Enterobacteria (CFU g^{-1})	Total viable counts (CFU g^{-1})	Molds and yeasts (CFU g^{-1})
Raw lemon pomace	194±6.20[a]	1,240±80.20[a]	295±12.30[a]
Lemon pomace powder	14±2.04[b]	580±25.40[b]	65±4.80[b]

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p < 0.05$)

Lario et al. (2004) determined the microbial count of lemon fiber treated under different conditions such as raw fiber, washed and dried fiber, and raw dried fiber. This study concluded that proper treatment and drying decreased the microbial count to an acceptable range for further preservation and utilization of lemon fiber. Reduction in the microbial count of dried lemon pomace powder, which might be due to Maillard reaction during heating, also caused extensive browning of the final powder. Maillard reaction compounds exhibited an inhibitory role towards microbial species. Final microbial counts in dried lemon pomace powder were acceptable for the preservation of powder, but if packed properly and stored under preservation treatments. Furan-type compounds, hydroxymethylfurfural, lactones, acids, and 3- hydroxy-2-pyrone as degradation products of L-ascorbic acid have been isolated and these compounds were identified as non-enzymatic browning products from lemon fruit concentrates and powders, with possible antimicrobial potential (Garcia-Salas et al., 2013). Different antioxidant and phenolic compounds like gallic acid, chlorogenic acid, catechin, caffeic acid, rutin, ferulic acid kaempferol and syringic acid have been found present in lemon peel powders, which play a role in inhibiting the growth of certain microorganisms (Mohdaly et al., 2022).

Abdel-Naeem et al. (2022) developed chicken patties by incorporation of peel powders of lemon, orange, grapefruit and banana, and conducted microbiological analysis. The results revealed that citrus peel powders possess less microbiological counts and the presence of antimicrobial agents like gallic acid in citrus peel powder resulted decrease in microbial counts in developed products as compared to control product. Lagana et al. (2022) investigated citrus pomace powder for water activity, moisture contents, and microbial counts, as well as correlated these parameters. They stated that the higher the moisture contents of the flour, the higher the water activity of the flour resulting in increased microbial counts will be.

Proximate composition of lemon pomace powder incorporated biscuits

The proximate composition of lemon peel powder-incorporated biscuits has been presented in Table 6. The data revealed that increasing the percentage of lemon peel powder in wheat flour resulted in an increase in the moisture, ash, fat and fiber contents of the developed biscuits. Wheat flours are usually deficient in ash, fat, and fiber contents, and lemon peel is a good source of these because of which these contents were raised in final formulated products. Fernandez-Gines et al. (2004) added lemon albedo to bologna sausages and found that presence of lemon albedo decreases fat content while increases the protein and fiber contents. Nassar et al. (2008) reported a decrease in protein and fat content in the citrus by-product (orange peel and pulp) substituted biscuits. Jurasova et al. (2011) developed biscuits by incorporating lemon and orange fiber formulations at different replacement levels and studied the chemical and functional properties of the biscuits. The findings revealed that this addition of citrus waste powders increased the technological and nutritional aspects of developed biscuits. Water activity of dough and biscuits formulated with lemon peel extracts was analyzed during the investigations and it was reported that the water-binding capacity of ingredients was improved due to the addition of lemon extracts, which reduced water evaporation during the baking process resulting in good quality biscuits with optimum moisture (Imeneo et al., 2021).

Results showing similarity with researchers were also noted in the findings of Srivastava et al. (2015) when they developed biscuits with different replacement levels of lemon peel powder. Ojha and Thapa (2017) determined and compared the chemical composition of control biscuits and biscuits with 6% mandarin peel powder and reported an increase in crude fiber, ash, fat carotenoids, polyphenols, and antioxidant activity. In their findings, ascorbic acid was not detected in control biscuits developed without the addition of mandarin peel powder, but the addition of mandarin peel powder resulted in the presence of ascorbic acid in formulated nutritional biscuits. These results were sufficient to conclude that citrus by-products (peel, pomace, fiber) have strong potential to boost the nutritional status of food products, especially bakery items, if incorporated at suitable levels to control the technological, physical, and sensorial attributes of developed products. Findings of Roy et al. (2021) also supported the results of present study, when they used both blanched and unblanched lemon peel powder to incorporate in wheat flour for development of formulated biscuits. Supportive results were also observed in the findings of Rani et al. (2020). Lagana et al. (2022) calculated moisture contents and water activity of biscuits developed with different replacement levels of

Table 6. Proximate composition of lemon pomace powder incorporated biscuits

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fiber (%)
T_0	5.50±0.23^c	6.00±0.05^a	18.60±0.35^d	1.28±0.11^a	2.95±0.14^d
T_1	6.00±0.20^c	5.81±0.04^b	22.20±0.34^c	1.49±0.17^a	6.45±0.17^c
T_2	7.00±0.17^b	5.25±0.05^c	25.80±0.36^b	1.59±0.11^a	9.10±0.17^b
T_3	8.00±0.21^a	4.95±0.03^d	29.60±0.34^a	1.74±0.14^a	12.40±0.20^a

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p<0.05$). T0 = biscuits with 0% lemon pomace powder and 100% wheat flour, T1 = biscuits with 5% lemon pomace powder and 95% wheat flour, T2 = biscuits with 10% lemon pomace powder and 90% wheat flour, T3 = biscuits with 15% lemon pomace powder and 85% wheat flour

citrus pomace powder and observed a significant increase in moisture contents and water activity of biscuits with an increase in the level of citrus pomace powder, and they linked this increase with the increase in fiber contents of the biscuits as fiber has the ability to retain moisture.

The addition of fruit and vegetable peels and their powders in wheat flour has gained importance in recent times to develop formulated functional and pharma food products. Recent investigations made by Hussain et al. (2022) on biscuits developed by the addition of pumpkin peel powder have proven that ash, fat and fiber contents of added peel powder biscuits were found high as compared to simple wheat flour biscuits. It was also reported that formulated functionalized biscuits contain sufficient amounts of total phenolic, flavonoid, carotenoid and mineral contents, which were contributed by the fruit peels.

Organoleptic properties of lemon pomace powder incorporated biscuits

Sensory characteristics of wheat flour biscuits as influenced by the incorporation of 0, 5, 10 and 15% of dried lemon fiber powder have been outlined in Table 7. The data revealed that all fortified biscuits containing up to 10% of dried lemon pomace powder improved all studied sensory characteristics. The addition of 15% lemon pomace powder improved texture but lowered the flavor and taste scores, thus affecting the overall acceptability. Yousaf et al. (2012) recommended the use of 10% orange peel powder supplementation to prepare biscuits with good quality and acceptable sensory attributes. Chen et al. (1988) reported that lemon and apple fibers because of their high water-holding capacities play an important role in improving the technological properties of bakery products. Al-Janabi and Yasen (2022) studied the effect of the incorporation of orange peel powder on sensory attributes of manufactured biscuits and concluded that 8% to 16% replacement level resulted positivity of sensorial characteristics like color, shape, flavor, texture and overall acceptability. Lower mold and yeast counts were observed in lemon extracts added dough, whereas after baking no yeast or mold count was observed in functionalized biscuits developed by Imeneo et al. (2021), strengthening the statements of incorporation of lemon peels in food products to obtain good quality acceptable items.

Jurasova et al. (2011) prepared powders from lemon and orange by-products and after chemical and functional analyses of these powders developed biscuits by replacing white flour with 5%, 10% and 15% powders of lemon and orange by-product powders. Replacement level up to 10% provided optimum results during sensory evaluation of biscuits, close to the control biscuits, whereas 15% replacement level was no accepted as required by the evaluators. Orange waste powder incorporated biscuits got relatively higher scores as compared to lemon waste powder-

Table 7. Organoleptic properties of lemon pomace powder incorporated biscuits

Treatment	Flavor	Texture	Taste	Appearance	Overall acceptability
T_0	6.58±0.16^b	6.47±0.19^a	6.84±0.17^a	6.16±0.19^b	6.58±0.14^b
T_1	7.32±0.17^a	6.95±0.17^a	7.32±0.17^a	7.21±0.12^a	7.58±0.11^a
T_2	7.45±0.19^a	6.77±0.16^a	6.95±0.17^a	7.37±0.15^a	7.46±0.15^a
T_3	6.95±0.25^b	5.93±0.22^b	6.11±0.25^b	6.45±0.18^b	6.77±0.16^b

Note: Mean scores within the columns followed by the same alphabetical letter are not significantly different ($p<0.05$). T0 = biscuits with 0% lemon pomace powder and 100% wheat flour, T1 = biscuits with 5% lemon pomace powder and 95% wheat flour, T2 = biscuits with 10% lemon pomace powder and 90% wheat flour, T3 = biscuits with 15% lemon pomace powder and 85% wheat flour

Figure 3. Biscuits with different replacement levels of lemon pomace powder

Note: T0 = biscuits with 0% lemon pomace powder and 100% wheat flour, T1 = biscuits with 5% lemon pomace powder and 95% wheat flour, T2 = biscuits with 10% lemon pomace powder and 90% wheat flour, T3 = biscuits with 15% lemon pomace powder and 85% wheat flour

incorporated biscuits. Srivastava et al. (2015) prepared nutritional biscuits by incorporating lemon peel powder in wheat flour at different proportions and conducted organoleptic analyses of biscuits to check the most suitable formulation and reported that up to 5% replacement level got good scores for color, taste, flavor, texture, and overall acceptability. Ojha and Thapa (2017) reported that biscuits prepared with 6% mandarin peel powder got good scores, compared with the control treatment. Studies by Roy et al. (2021) recommended the incorporation of both blanched and unblanched lemon peel powders for the development of biscuits, which can be marketed commercially to consumers. Results provided by Rani et al. (2020) also showed a similar trend as found in present studies. Lagana et al. (2022) developed functional biscuits by the incorporation of citrus pomace powder at different replacement levels and observed that a 10% replacement level of citrus pomace powder provided good quality nutritious biscuits with increased TPC, TFC and antioxidant activities.

Studies conducted by Hussain et al. (2022) on biscuits developed by incorporation of fruit and vegetable peels powder at different replacement levels have provided similar results and it was suggested that a 5% to 10% replacement level of fruit peel powder was suitable to develop good quality biscuits with acceptable sensory scores. The decrease in flavor scores of biscuits with a 15% replacement of lemon pomace powder might be attributed to the increased number of flavoring compounds present in lemon pomace, while decreased scores of tastes with an increased level of lemon pomace powder have been reported due to the presence of more polyphenols. Natural pigments present in lemon pomace have imparted a more yellowish color to 15% lemon pomace powder biscuits, the reason behind low scores for appearance and overall acceptability of biscuits. Abdel-Naeem et al. (2022) reported that the incorporation of lemon, orange, grapefruit, and banana peel powders for the development of chicken patties increased organoleptic scores in terms of color, aroma, appearance, and tenderness. Developed final products were appreciated by the judges, opening new paths for the development of dairy, bakery, beverage and meat products by incorporation of citrus peel powders. Control biscuits and different treatment biscuits have been presented in Figure 3.

CONCLUSIONS

Pomace left after extraction of lemon juice, when converted into powder has been proven excellent source of nutritional ingredients. Microbiological analyses of lemon pomace powder revealed lower bacterial, yeast, and mold counts, encouraging its application in different food products. Dry matter and pH of lemon pomace powder were found greater, while water activity was lesser, than of raw lemon pomace. Colorimetric analysis revealed that $L*$ and $b*$ values were decreased, while $a*$ value was increased when lemon pomace was converted to dried powder. The incorporation of lemon pomace powder in wheat flour at 0%, 5% to 10% replacement levels produced good quality biscuits with increased ash, fat, and fiber contents having acceptable flavor, taste, texture, appearance, and overall acceptability. Lemon pomace powder can be prepared by implementing various novel and innovative technologies, which can preserve nutritional values and functional bioactives. Lemon pomace powder can be used as good source of vitamin C and carotenoids. Potential food applications of lemon pomace powder may include bakery products, sausages, snacks, extrusion products, confectionery, beverages, and meat products. Effective and efficient waste handling technologies could be implemented to produce by-products from lemon juice waste streams.

ACKNOWLEDGEMENT

The authors are grateful to the Department of Food Science and Technology, Ayyub Agricultural Research Institute, Faisalabad, Pakistan, and the Institute of Food Science and Nutrition, University of Sargodha, Sargodha, Pakistan, for facilitating this research, by providing resources. No funds were availed for this research work.

REFERENCES

Abdel-Naeem, H. H., Elshebrawy, H. A., Imre, K., Morar, A., Herman, V., Pașcalau, R., & Sallam, K. I. (2022). Antioxidant and antibacterial effect of fruit peel powders in chicken patties. *Foods*, *11*(3), 301. https://doi.org/10.3390/foods11030301

Al-Janabi, E. S. H., & Yasen, S. S. (2022). Study of the functional, physical and sensory properties of wheat flour, orange peel powder and manufactured biscuits. *Eurasian Medical Research Periodical*, *8*, 7–17. Retrieved from https://geniusjournals.org/index.php/emrp/article/view/1332

American Association of Cereal Chemists (AACC). (2000). *Approved Methods Committee. Approved methods of the American association of cereal chemists* (Vol. 1). Amer Assn of Cereal Chemists. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Approved+methods+of+the+American+association+of+cereal+chemists+&btnG=

Association of Official Analytical Chemists (AOAC). (1995). *Official Methods of Analysis*, 15th ed. Association of Official Analytical Chemist. Washington, DC. Retreived from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Official+Methods+of+Analysis%2C+15th+ed&btnG=

Bakshi, G., & Ananthanarayan, L. (2022). Characterization of lemon peel powder and its application as a source of pectin degrading enzyme in clarification of cloudy apple juice. *Journal of Food Science and Technology*, *59*(7), 2535–2544. https://doi.org/10.1007/s13197-021-05270-7

Bellavite, P., & Donzelli, A. (2020). Hesperidin and SARS-CoV-2: New light on the healthy function of citrus fruits. *Antioxidants*, *9*(8), 742. https://doi.org/10.3390/antiox9080742

Chen, H., Rubenthaler, G. L., Leung, H. K., & Baranowski, J. D. (1988). Chemical, physical, and baking properties of apple fiber compared with wheat and oat bran. *Cereal chem*, *65*(3), 244–247. Retrieved from https://www.cerealsgrains.org/publications/cc/backissues/1988/documents/65_244.pdf

FAO. (2022). Food and Agriculture Organization of the United Nation. FAOSTAT. Retrieved from http://www.fao.org/faostat/en/#data/QC

Fernandez, M., Borroto, B., Larrauri, J. A., & Sevillano, E. (1993). Fibra dietetica de toronja: producto natural sin aditivos. *Alimentaria*, *247*, 81–83. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Fibra+dietetica+de+toronja%3A+producto+natural+sin+aditivos&btnG=

Fernandez, M., Sevillano, E., Larrauri, J. A., Borroto, B., & Nunez, M. (1995). Influencia de las condiciones de lavado en la obtencion de fibra dietetica de toronja (*Citrus paradisi* Osbeek). *Alimentaria*, *260*, 19–21. Retrieved from https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=3512909

Fernandez-Gines, J. M., Fernandez-Lopez, J., Sayas-Barbera, E., Sendra, E., & Perez-Alvarez, J. A. (2003). Effect of storage conditions on quality characteristics of bologna sausages made with citrus fiber. *Journal of food science*, *68*(2), 710–714. https://doi.org/10.1111/j.1365-2621.2003.tb05737.x

Fernández-Ginés, J. M., Fernández-López, J., Sayas-Barberá, E., Sendra, E., & Perez-Alvarez, J. A. (2004). Lemon albedo as a new source of dietary fiber: Application to bologna sausages. *Meat science*, *67*(1), 7–13. https://doi.org/10.1016/j.meatsci.2003.08.017

Fernandez-Lopez, J., Fernández-Ginés, J. M., Aleson-Carbonell, L., Sendra, E., Sayas-Barberá, E., & Pérez-Alvarez, J. A. (2004). Application of functional citrus by-products to meat products. *Trends in Food Science & Technology*, *15*(3–4), 176–185. https://doi.org/10.1016/j.tifs.2003.08.007

Garau, M. C., Simal, S., Femenia, A., & Rosselló, C. (2006). Drying of orange skin: Drying kinetics modelling and functional properties. *Journal of food engineering*, *75*(2), 288–295. https://doi.org/10.1016/j.jfoodeng.2005.04.017

Garcia-Salas, P., Gómez-Caravaca, A. M., Arráez-Román, D., Segura-Carretero, A., Guerra-Hernández, E., García-Villanova, B., & Fernández-Gutiérrez, A. (2013). Influence of technological processes on phenolic compounds, organic acids, furanic derivatives, and antioxidant activity of whole-lemon powder. *Food chemistry*, *141*(2), 869–878. https://doi.org/10.1016/j.foodchem.2013.02.124

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/10.1016/j.indcrop.2012.03.009

Gorinstein, S., Martín-Belloso, O., Park, Y. S., Haruenkit, R., Lojek, A., Ciz, M., ... & Trakhtenberg, S. (2001). Comparison of some biochemical characteristics of different citrus fruits. *Food chemistry*, *74*(3), 309–315. https://doi.org/10.1016/S0308-8146(01)00157-1

Guiné, R. P., & Barroca, M. J. (2012). Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper). *Food and bioproducts processing*, *90*(1), 58–63. https://doi.org/10.1016/j.fbp.2011.01.003

Haider, M. R., Abrar, M., Mehmood, A., Hussain, A., & Nasir, M. U. (2016). Effect of different combinations of gums and emulsifiers on the quality of bread: Gums and emulsifiers for bread quality. *Biological Sciences-PJSIR*, *59*(1), 33–37. Retrieved from http://www.v2.pjsir.org/index.php/biological-sciences/article/download/53/40

Hussain, A., Kausar, T., Din, A., Murtaza, A., Jamil, M. A., Noreen, S., & Iqbal, M. A. (2021). Antioxidant and antimicrobial properties of pumpkin (*Cucurbita maxima*) peel, flesh and seeds powders. *Journal of Biology*, *Agriculture and Healthcare*, *11*(6), 42–51. https://doi.org/10.7176/JBAH/11-6-05

Hussain, A., Kausar, T., Din, A., Murtaza, M. A., Jamil, M. A., Noreen, S., ... & Ramzan, M. A. (2021). Determination of total phenolic, flavonoid, carotenoid, and mineral contents in peel, flesh, and seeds of pumpkin (*Cucurbita maxima*). *Journal of Food Processing and Preservation*, *45*(6), e15542. https://doi.org/10.1111/jfpp.15542

Hussain, A., Kausar, T., Jamil, M. A., Noreen, S., Iftikhar, K., Rafique, A., ... & Ali, A. (2022). *In vitro* role of pumpkin parts as pharma-foods: Antihyperglycemic and antihyperlipidemic activities of pumpkin peel, flesh, and seed powders, in alloxan-induced diabetic rats. *International Journal of Food Science*, *2022*, 4804408. https://doi.org/10.1155/2022/4804408

Hussain, A., Kausar, T., Murtaza, M. A., Jamil, M. A., Iqbal, M. A., Majeed, M. A., ... & Mehmood, A. (2022). Production, characterization, food application and biological study of powder of pumpkin (*Cucurbita maxima*) parts (peel, flesh and seeds). *Pure and Applied Biology*, *12*(1), 48–60. http://dx.doi.org/10.19045/bspab.2023.120006

Hussain, A., Kausar, T., Sehar, S., Sarwar, A., Ashraf, A. H., Jamil, M. A., ... & Majeed, M. A. (2022). A Comprehensive review of functional ingredients, especially bioactive compounds present in pumpkin peel, flesh and seeds, and their health benefits. *Food Chemistry Advances*, *1*, 100067. https://doi.org/10.1016/j.focha.2022.100067

Hussain, A., Kausar, T., Sehar, S., Sarwar, A., Ashraf, A. H., Jamil, M. A., ... & Quddoos, M. Y. (2022). Determination of total phenolics, flavonoids, carotenoids, β-carotene and DPPH free radical scavenging activity of biscuits developed with different replacement levels of pumpkin (*Cucurbita maxima*) peel, flesh and seeds powders. *Turkish Journal of Agriculture-Food Science and Technology*, *10*(8), 1506–1514. https://doi.org/10.24925/turjaf.v10i8.1506-1514.5129

Hussain, A., Kausar, T., Sehar, S., Sarwar, A., Ashraf, A. H., Jamil, M. A., ... & Zerlasht, M. (2022). Utilization of pumpkin, pumpkin powders, extracts, isolates, purified bioactives and pumpkin based functional food products; A key strategy to improve health in current post COVID 19 period; an updated review. *Applied Food Research*, *2*(2), 100241. https://doi.org/10.1016/j.afres.2022.100241

Imeneo, V., Romeo, R., Gattuso, A., De Bruno, A., & Piscopo, A. (2021). Functionalized biscuits with bioactive ingredients obtained by Citrus lemon pomace. *Foods*, *10*(10), 2460. https://doi.org/10.3390/foods10102460

Jiang, H., Zhang, W., Xu, Y., Chen, L., Cao, J., & Jiang, W. (2022). An advance on nutritional profile, phytochemical profile, nutraceutical properties, and potential industrial applications of lemon peels: A comprehensive review. *Trends in Food Science & Technology*, *124*, 219–236. https://doi.org/10.1016/j.tifs.2022.04.019

Johnson, I. T. (2012). Dietary fiber. In *Present knowledge in nutrition* (eds J.W. Erdman, I.A. Macdonald and S.H. Zeisel). https://doi.org/10.1002/9781119946045.ch8

Jurasova, Z. K. J. K. M., & Kukurova, K. (2011). Application of citrus dietary fibre preparations in biscuit production. *Journal of Food and Nutrition Research*, *50*(3), 182–190. Retrieved from https://www.researchgate.net/profile/Kristina-Kukurova/publication/279903964_Application_of_citrus_dietary_fibre_preparations_in_biscuit_production/links/55a8dbfc08aea994671e84f0/Application-of-citrus-dietary-fibre-preparations-in-biscuit-production.pdf

Lagana, V., Giuffrè, A. M., De Bruno, A., & Poiana, M. (2022). Formulation of biscuits fortified with a flour obtained from bergamot by-products (*Citrus bergamia*, Risso). *Foods*, *11*(8), 1137. https://doi.org/10.3390/foods11081137

Lario, Y., Sendra, E., Garcıa-Pérez, J., Fuentes, C., Sayas-Barberá, E., Fernández-López, J., & Perez-Alvarez, J. A. (2004). Preparation of high dietary fiber powder from lemon juice by-products. *Innovative Food Science & Emerging Technologies*, *5*(1), 113–117. https://doi.org/10.1016/j.ifset.2003.08.001

Larrauri, G. J. A. (1994). Utilización de los hollejos cítricos y las cáscaras de piñas como fuentes de fibra dietética en Cuba. *Alimentaria*, *252*, 57–59. Retrieved from https://scholar.google.com/scholar?hl=id&as_sdt=0%2C5&q=Utilizaci%C3%B3n+de+los+hollejos+c%C3%ADtricos+y+las+c%C3%A1scaras+de+pi%C3%B1as+como+fuentes+de+fibra+diet%C3%A9tica+en+Cuba&btnG=

Larrauri, J. A. (1999). New approaches in the preparation of high dietary fibre powders from fruit by-products. *Trends in Food Science & Technology*, *10*(1), 3–8. https://doi.org/10.1016/S0924-2244(99)00016-3

Mohdaly, A. A. A., Roby, M. H., Sultan, S. A. R., Groß, E., & Smetanska, I. (2022). Potential of low cost agro-industrial wastes as a natural antioxidant on carcinogenic acrylamide formation in potato fried chips. *Molecules*, *27*(21), 7516. https://doi.org/10.3390/molecules27217516

Nassar, A. G., AbdEl-Hamied, A. A., & El-Naggar, E. A. (2008). Effect of citrus by-products flour incorporation on chemical, rheological and organoleptic characteristics of biscuits. *World Journal of Agricultural Sciences*, *4*(5), 612–616. Retrieved from https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=02d370d799c5e2505d7d59d2a8419b2d8df405f2

Ojha, P., & Thapa, S. (2017). Quality evaluation of biscuit incorporated with mandarin peel powder. *Scientific Study & Research. Chemistry & Chemical Engineering, Biotechnology, Food Industry*, *18*(1), 19–30. Retrieved from https://www.researchgate.net/profile/Pravin-Ojha/publication/314262228_Quality_evaluation_of_biscuit_incorporated_with_mandarin_peel_powder/links/58bea4f4aca2727fdb7b6300/Quality-evaluation-of-biscuit-incorporated-with-mandarin-peel-powder.pdf

Papoutsis, K., Pristijono, P., Golding, J. B., Stathopoulos, C. E., Scarlett, C. J., Bowyer, M. C., & Vuong, Q. V. (2016). Impact of different solvents on the recovery of bioactive compounds and antioxidant properties from lemon (*Citrus limon* L.) pomace waste. *Food* *science and biotechnology*, *25*(4), 971–977. https://doi.org/10.1007/s10068-016-0158-8

Quiles, A., Campbell, G. M., Struck, S., Rohm, H., & Hernando, I. (2018). Fiber from fruit pomace: A review of applications in cereal-based products. *Food Reviews International*, *34*(2), 162–181. https://doi.org/10.1080/87559129.2016.1261299

Rani, V., Sangwan, V., & Malik, P. (2020). Orange peel powder: A potent source of fiber and antioxidants for functional biscuits. *International Journal of Current Microbiology and Applied Sciences*, *9*, 1319–1325. https://doi.org/10.20546/ijcmas.2020.909.167

Robertson, J. A., de Monredon, F. D., Dysseler, P., Guillon, F., Amado, R., & Thibault, J. F. (2000). Hydration properties of dietary fibre and resistant starch: a European collaborative study. *LWT-Food Science and Technology*, *33*(2), 72–79. https://doi.org/10.1006/fstl.1999.0595

Rocha, A. M. C. N., & Morais, A. M. M. B. (2003). Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes. *Food control*, *14*(1), 13–20. https://doi.org/10.1016/S0956-7135(02)00046-4

Roy, J., Roy, S., Ali, M. J., Hossain, M. R., & Sarker, M. S. H. (2021). Effect of drying temperature on physiochemical properties of powder from blanched and unblanched lemon peel and sensory quality evaluation of the powder fortified biscuits. *Journal of Food Engineering and Technology*, *10*(1), 9–18. https://doi.org/10.32732/jfet.2021.10.1.9

Sankalpa, K. B., Ramachandra, C. T., Dinesha, B. L., Nidoni, U. K., Hiregoudar, S., & Beladhadi, R. V. (2017). Effect of different drying and grinding methods on biochemical properties of sweet orange peel powder. *Asian Journal of Dairy and food Research*, *36*(3), 260–263. https://doi.org/10.18805/ajdfr.v36i03.8975

Singh, A., & Kumar, P. (2018). Gluten free approach in fat and sugar amended biscuits: A healthy concern for obese and diabetic individuals. *Journal of Food Processing and Preservation*, *42*(3), e13546. https://doi.org/10.1111/jfpp.13546

Srivastava, N., Yadav, K. C., Verma, P., Kishore, K., & Rout, S. (2015). Development of lemon peel powder and its utilization in preparation of biscuit by different baking methods. *International Journal for Scientific Research & Development*, *3*(8), 2321–0613. Retrieved from https://www.researchgate.net/profile/Sandeep-Rout-2/publication/322702164_Development_of_Lemon_Peel_Powder_and_its_Utilization_in_Preparation_of_Biscuit_by_Different_Baking_Methods/links/5a6a3b820f7e9b1c12d17fc2/Development-of-Lemon-Peel-Powder-and-its-Utilization-in-Preparation-of-Biscuit-by-Different-Baking-Methods.pdf

Steel, R., Torrie, J., & Dickey, D. (1997). *Principles and procedures of statistics A biometrical approach 3rd ed, pp. 334–381*. New York, USA: McGraw Hill Book Company Inc. Retrieved from https://www.cabdirect.org/cabdirect/abstract/19810721475

Suri, S., Singh, A., & Nema, P. K. (2021). Recent advances in valorization of citrus fruits processing waste: a way forward towards environmental sustainability. *Food Science and Biotechnology*, *30*, 1601–1626. https://doi.org/10.1007/s10068-021-00984-y

Tekgul, Y., & Baysal, T. (2018). Comparative evaluation of quality properties and volatile profiles of lemon peels subjected to different drying techniques. *Journal of Food Process Engineering*, *41*(8), e12902. https://doi.org/10.1111/jfpe.12902

Thebaudin, J. Y., Lefebvre, A. C., Harrington, M., & Bourgeois, C. M. (1997). Dietary fibres: Nutritional and technological interest. *Trends in Food Science & Technology*, *8*(2), 41–48. https://doi.org/10.1016/S0924-2244(97)01007-8

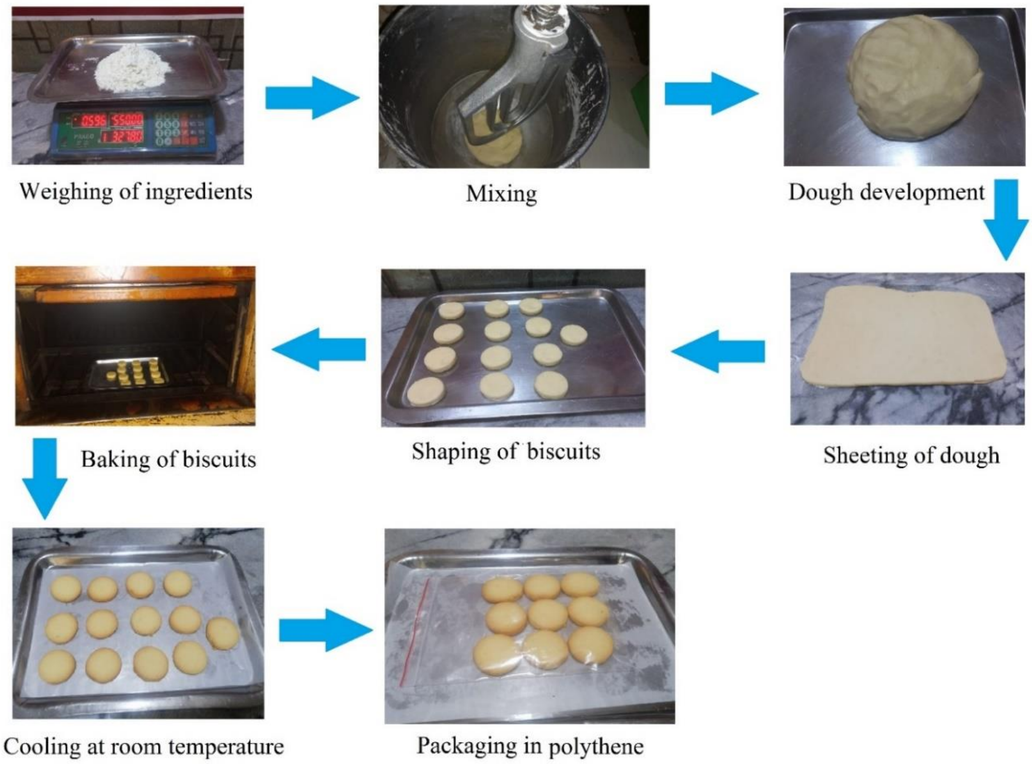
Trumbo, P., Schlicker, S., Yates, A. A., & Poos, M. (2002). Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. *Journal of American Dietary Association*, *102*(11), 1621–1631. https://doi.org/10.1016/S0002-8223(02)90346-9

Tsikritzi, R., Moynihan, P. J., Gosney, M. A., Allen, V. J., & Methven, L. (2014). The effect of macro-and micro-nutrient fortification of biscuits on their sensory properties and on hedonic liking of older people. *Journal of* *the Science of Food and Agriculture*, *94*(10), 2040–2048. https://doi.org/10.1002/jsfa.6522

Tudorica, C. M., Kuri, V., & Brennan, C. S. (2002). Nutritional and physicochemical characteristics of dietary fiber enriched pasta. *Journal of agricultural and food chemistry*, *50*(2), 347–356. https://doi.org/10.1021/jf0106953

Wang, L., Xu, H., Yuan, F., Fan, R., & Gao, Y. (2015). Preparation and physicochemical properties of soluble dietary fiber from orange peel assisted by steam explosion and dilute acid soaking. *Food Chemistry*, *185*, 90–98. https://doi.org/10.1016/j.foodchem.2015.03.112

Youssef, M. K. E., Ali, H. M., & El-Manfaloty, M. M. (2013). Nutritional assessment of wheat biscuits and fortified wheat biscuits with carob pod powder (*Ceratonia siliqua* L.). *Food and Public Health*, *3*(6), 336–340. Retrieved from http://article.sapub.org/10.5923.j.fph.20130306.11.html



Appendix 1. Graphical flow diagram of preparation of lemon pomace incorporated biscuits