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Impact of Integrated Ultra Violet-Ozone Treatment on Textural and Structural Properties of Dough Made of Natural Fiber Based Agro Residues

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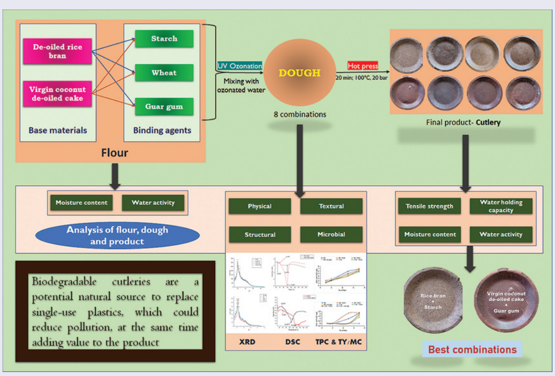
ABSTRACT

In this study, de-oiled rice bran (RB) and virgin coconut oil cake (VCOC) were selected as base materials. Corn starch, wheat bran, and guar gum were taken as binding agents. The doughs were treated with combined Ultraviolet (UV) (1000 µW/cm2 for 15 min) and Aqueous Ozone (AO) (3 mg/L, exposure time 5 min and pH of 4). The effect of these non-thermal treatments on microbial log reduction, textural characteristics, glass transition (Tg), and crystallinity was studied and compared with the control. The results for all samples, dough raising capacities differed widely by 10–30%. Bulk Density and True Density were 1.6 to 2.5 g/cm3 and 2.3 to 3.3 g/cm3. X-Ray Diffraction indicated 30–45% crystallinity, and crystallite size ranges between 0.54 and 0.90 nm. DSC indicated Tg and melting point between 49°C-55°C and 98°C-101°C for RB dough and at 54°C-60°C and 107°C-134°C for VCOC dough samples. UV with AO treated dough showed a maximum of 5.2 log microbial reduction compared to the untreated sample. The developed RB and wheat bran combination demonstrated the highest tensile strength (0.62 MPa) whereas RB-starch combination had the minimum water absorption (1.33 ml/min). This indicates the ability of additives to improve the characteristics of biodegradable cutlery made from agricultural residues.



KEYWORDS
Biodegradable cutleries; binding agents; UV; ozonation; de-oiled rice bran; virgin coconut oil cake; glass transition temperature

关键词
可生物降解餐具; 结合剂; 紫外臭氧化; 脱脂米糠; 初榨椰子油蛋糕; 玻璃化转变温度

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摘要
在本研究中，选择脱油米糠（RB）和初榨椰子油饼（VCOC）作为基础材料．以玉米淀粉、麦麸和瓜尔胶为粘合剂．面团用紫外线（UV）（1000 μW/cm2，持续15分钟）和臭氧水溶液（AO）（3 mg/L，暴露时间5分钟，pH值为4）处理．研究了这些非热处理对微生物对数减少、结构特征、玻璃化转变（Tg）和结晶度的影响，并与对照进行了比较．所有样品的结果表明，面团发酵能力相差10-30%．堆积密度和真实密度分别为1.6至2.5 g/cm3和2.3至3.3 g/cm3。X射线衍射表明结晶度为30-45%，晶粒尺寸范围为0.54至0.90 nm．DSC显示RB面团的Tg和熔点分别在49°C-55°C和98°C-101°C之间，VCOC面团的Td和熔点分别为54°C-60°C和107°C-134°C．与未经处理的样品相比，经AO处理的面团的UV显示最大5.2 log微生物减少．开发的RB和麦麸组合表现出最高的拉伸强度（0.62MPa），而RB淀粉组合具有最小的吸水率（1.33 ml/min）．这表明添加剂能够改善由农业残留物制成的可生物降解餐具的特性．

1. Introduction

Governments and organizations all across the globe are now focusing on reducing the burden of environmental waste by reusing or recycling these waste items. Furthermore, the production of a high-value product from waste is sought, particularly if the wastes were previously of no value (Hasanin 2021). India, being an agrarian country with about 60% of people engaged in agriculture and related activities, has the potential to resolve the problem by effective use of agro-wastes/byproducts, which could also be effective in mitigating the adverse environmental effects caused by the disposal of these wastes, at the same time adding income source to the farmers. The agro residues (wheat bran fiber, rice bran (RB), Virgin coconut oil cake (VCOC)) have natural fiber called dietary fiber, lignin, cellulose and hemicellulose responsible for the binding action to form biodegradable cutlery. Therefore, the utilization of these agro-wastes provides immense opportunities as an alternative to single-use plastics (Dordevic et al. 2021). Properties of cutlery, viz. mechanical properties, water holding capacity, and shelf life, depend primarily on dough properties such as rheology, structure, texture, granularity, and elasticity. Therefore, it is quintessential to analyze and optimize the properties of dough to obtain good-quality cutleries. Virgin coconut oil cake (VCOC) is an under-exploited byproduct from virgin coconut oil industries. Besides a rich source of nutrients such as dietary fiber polyphenols, coconut de-oiled cake has remained an underutilized byproduct. It is either used as animal feed or thrown as waste (Pandiselvam et al. 2019). These are rich in nutrients, fibers, vitamins, and minerals and contain various phytochemicals such as alkaloids, flavonoids, phenols, tannins, and other important bioactive elements (Ajayan and Hebsur 2020) and can be utilized in functional and healthy foods in extrudates, bakery, and confectionery products. Coconut flours also have the potential to be used in pharmaceuticals, cosmetics and binderless board production (Manikantan, Kingsly Ambrose, and Alavi 2016). The consistency in flow properties of coconut de-oiled cake flour is critical since it can affect the quality of the end product and the efficiency of the process. On the other hand, rice bran is a byproduct of rice milling, is widely used as cattle and poultry feed, and is used for the production of rice bran oil in many countries. Rice bran consists of 20–29% oil, 10–15% proteins, and 20–27% fiber (Mishra 2017). Whole fat rice bran contains high availability of fiber, and low cost of raw materials, making it a good source of raw material for preparing dough for biodegradable cutleries.

Non-thermal technologies have been widely used for the surface modification of polymers. Ozone is a strong oxidant reported to have a wide range of applications in the food industry. Ozone could be applied either in gaseous or aqueous form for the decontamination of agricultural and food products. Aqueous ozone (AO) treatment effectively reduces microbial load, thereby improving the quality and shelf life of food products (Pandiselvam et al. 2019; Sivaranjani et al. 2021). However, at higher concentrations, AO owing to its high oxidative potential can impart negative effects on the quality of treated produce, and as such, there has to be a threshold value for concentration and time for ozone treatment depending on the specificity of produce (Pandiselvam et al. 2020). Aqueous ozone improved the textural properties of food in terms of hardness, gumminess, cohesiveness, and adhesiveness as compared to control, which might be explained that the oxidation of aqueous ozone promoted the cross-linking degree of proteins in food during mixing, kneading, fermentation (Aslam, Shafiq Alam, and Pandiselvam 2021). Ultraviolet (UV) radiation is a well-known technology used to enhance the rate of heat and mass transfer providing high end product quality in a short time (Teng, Zhang, and Mujumdar 2021). UV treatment has been applied efficaciously for the inactivation of microbes to enhance the shelf life of dough. Moreover, it improves the textural and rheological properties of dough. Since the improved quality of dough is the essential characteristic determining the quality of the final product, i.e. biodegradable cutlery, which is then to be used by humans as the end consumers, a study was taken up to analyze the applicability of VCOC and de-oiled rice bran as a natural substitute for synthetic polymers in making biodegradable cutleries and the effect of UV and ozonation as a pre-treatment to improve the physical, textural and structural properties of dough used for the production of biodegradable cutleries.

2. Materials and methods

2.1. Raw materials

De-oiled rice bran (*Oryza sativa*) and wheat bran (*Triticum aestivum*) were procured from local markets, Chalai, Trivandrum, and VCOC (*Cocos nucifera*) obtained from Kasaragod, India, used as the base material for the study. Based on preliminary studies, food-grade corn starch (Desire Foods, Gujarat India), and guar gum (Urban Platter) were selected as binding agents.

2.2. Dough preparation

2.2.1. Flour preparation

Flour (150 g) of VCOC and RC was prepared by mixing 85% base material with 15% binding agents. About 127.5 g of the base material was taken and mixed with a 22.5 g binding agent, for making different compositions from RB and VCOC samples as base materials, with starch, wheat flour and guar gum as binding agents. This mixture is then treated with aqueous ozonized water. Untreated flour samples and a 15% binding agent were used as the control for studies.

2.2.2. Pre-treatment using aqueous ozone and UV treatment

2.2.2.1. a Aqueous ozone (AO). An Ozone generator, model EQ1; Ozonics generators, India, was used to produce ozone gas. Excess ozone gas was continually delivered to the ozone destructor through the exit pipe after being placed into a 2,500 mL glass jar. To generate ozone, an oxygen cylinder holding 99.99% oxygen was utilized as the feed gas into the generator. The ozone gas formed bubbles as it traveled through the diffuser, and these bubbles came into contact with water.

2.2.2.2. b UV treatment. A germicidal UV lamp (Sankyo Denki, Japan) was used to provide UV irradiation for 15 minutes at a wavelength of 254 nm and a power of 30 W (G30T8). 100 g of dough and fresh powders were speeded in trays sized 50 by 30 cm and exposed to radiation from 15 cm distance. All of the experiments were repeated thrice. The moisture content of the obtained dough was determined using AACC (2000) method 44–15.02 at the end of each test. Treated samples were transferred aseptically to sterile carton trays and stored in the dark until they were tested.

2.2.3. Dough preparation from pretreated flour

Following pre-treatment, the powder mix was mixed with AO-treated distilled water (dosage 3 mg/L for 5 min time of exposure) for making the various combinations of dough (for VCOC – 30 ml water, de-oiled RB – 70 ml water) followed by mixing in a Rotomixer (Plasto Mek, Quilandy, India) operating at 780 rpm for 15 minutes at 35°C temperatures.

2.3. Physical characteristics of dough

2.3.1. Moisture content

The moisture content was analyzed by following AACC method No. 44-15A (AACC 2000).

$$\%Moisture = \frac{\text{moisture loss}}{original\ weight\ of\ sample} \times 100$$

2.3.2. Water activity

A water activity meter (Labtouch aw, Novasina, Lachen, Switzerland) was used to measure the water activity of the prepared dough samples. Samples were analyzed at 27°C, and the measurements of each sample were taken in triplicates.

2.3.3. Dough raising capacity

Dough-raising capacity was calculated by slightly modifying the method proclaimed by (Malkanthi and Umadevi 2018).

$$\text{Dough raising capacity}(\%) = \frac{(\text{final level reading} - \text{initial level reading})}{\text{initial level reading}} * 100$$

2.3.4. Bulk and true density

Weighed dough samples were placed in the specimen holder of the Helium Pycnometer (AccuPyc 1330 Pycnometer, USA). The weighed sample was inserted into the machine and operated for 30 minutes. The true density of the product is determined using a pycnometer, whereas the bulk density is estimated using data obtained from the volumeter (Skendi and Papageorgiou 2021).

2.4. Structural characteristics of dough

2.4.1. X-Ray diffraction

A powder X-ray diffractometer (Malvern PANalytical PC controlled X-Ray Diffractometer, United Kingdom) was employed for crystallinity and structural analysis of dough samples (Skendi, Papageorgiou, and Papastergiadis 2021). The crystallinity index was calculated from the graph using the following equation.

$$Crystallinity\ index(\%) = \frac{Area\ of\ all\ crystalline\ peakes}{area\ of\ all\ crystalline\ and\ amorphous\ peaks} \times 100$$

2.4.2. Differential scanning calorimetry

The glass transition temperature (T_g) and melting temperature (T_m) of the specimens were determined using a differential scanning calorimeter (TA Instruments DSC Q1000) beneath an N_2 gas atmosphere at a rate of 10°C/min during a heating cycle between 20 and 200°C (Gowd, Shibayama, and Tashiro 2006).

2.5. Textural characteristics of dough

Textural characteristics of dough viz. Hardness, Adhesiveness, Cohesiveness, and Gumminess were analyzed using a computer-interfaced Texture profile analyzer (Model: EZ-SX 500 N, Shimadzu, Japan).

2.6. Microbial characteristics of dough

Microbial characteristics of prepared dough samples were done in terms of total plate count and total yeast count to analyze the presence of microbial content in the prepared dough. The samples were undergone serial dilution (tenfold times) using sterile saline solution and plated on nutrient agar (HiMedia), followed by incubation at 30°C for 72 h to calculate the total plate count (Gregirchak, Stabnikova, and Stabnikov 2020). Samples were plated on potato dextrose agar (HiMedia) and incubated for five days at 28°C to calculate the total yeast/mold count (Suo et al. 2020).

2.7. Analysis of biodegradable cutleries

The production of biodegradable plates is accomplished by hot press molding, using stainless steel hot press for 20 minutes, operating at 100°C temperature and 20 bar pressure. Parameters such as tensile strength (ASTM D638 2003), moisture content (AOAC 2005), water holding capacity (Wojnowska-Baryła, Kulikowska, and Bernat 2020), and water activity using water activity meter (Labtouch aw, Novasina, Lachen, Switzerland), of the final product were tested for the quality of the final product.

3. Statistical analysis

All e flour, dough, and final product analysis performed in triplicates, and the obtained results of each observation were further used to calculate the mean and standard deviation values for statistical analysis. The statistical analysis was performed using Microsoft Excel (Version 2016) and Origin Pro (Origin Pro 2021 Version 9.8) at a 5% level of significance.

4. Results and discussions

4.1. Physical characteristics of dough

The water activity of Ultraviolet (UV) with Aqueous ozone (AO) treated flours has a wide variation ranging from 0.506 to 0.757 aw (Table 1). The minimum water activity was incurred for Virgin Coconut Oil Cake (VCOC) and VCOC with starch as compared to other combinations and control. Lower water activity (aw) may be attributed to a reduced chance for microbial growth, which is desirable for good-quality dough. In general, the aw of 0.95 or above is required to enable microbial development (Tapia, Alzamora, and Chirife 2020). The water activity of used flour was within the acceptable range. Similarly, the moisture content of UV with AO-treated flour varied between 8.71 to 12.33%. The lower moisture content was obtained for RB dough due to the high crude fiber content. The combined UV and AO treatment effectively reduce flour and dough's water activity and moisture content. Similar findings were reported by Jemni et al. (2014). The drop in moisture and aw might be explained by the evaporation of date fruit water produced by UV treatment, the relatively high temperature, and moderate relative humidity. Campagna et al. (2020) reported that the reduction of moisture could be attributed to the soft heating determined by the long application of the energy by UV irradiation, which may increase the temperature caused by the mobilization and movement of water from the treated dough in longer treatment (15 to 150 min).

Dough raising capacities of the tested UV with AO treated dough differed widely by 10 and 30%. Compared to gums and bran, the minimum dough rising capacity was obtained for RB with starch dough and VCOC with starch-incorporated dough. This is due to increased water uptake by starch granules, which have been damaged by continuous UV exposure (Shanakhat et al. 2019). The dough raising property of the VCOC sample was better than with de-oiled RB. Lower dough raising capacity was required for the production of cutleries which requires compression and heat treatment. From a technological point of view, the reactivity of protein components improved following UV with AO treatment. The VCOC has higher protein content than RB and can cause a potential interaction

Table 1. Water activity and moisture content of flour (RB: De-oiled rice bran; VCOC: Virgin Coconut Oil Cake).

Composition	C_{RB}	RB	RB + Starch	RB + Wheat bran fiber	RB + Guar gum	C_{VCOC}	VCOC	VCOC + Starch	VCOC + Wheat bran fiber	VCOC + Guar gum
Water activity (aw)	0.698±.0158	0.631 ± 0.0035	0.757 ± 0.0121	0.697 ± 0.0076	0.615 ±0.0579	0.602 ± 0.0357	0.506 ±0.0465	0.506 ±0.0465	0.659 ±0.0300	0.674 ±0.0163
Moisture content (%)	09.035±.0745	08.716 ± 0.5393	10.073 ± 0.0643	10.550 ± 0.0866	09.933 ± 0.5508	10.920±.0967	10.350 ±0.2179	11.620 ±0.4530	12.333 ±0.7638	11.500 ±0.5020

C_{RB} = Control Rice bran (UV and aqueous ozone treatment), C_{VCOC}= Control Virgin Coconut De-Oiled Cake (UV and aqueous ozone treatment).

between protein and binder that leads to an upsurge in the water absorption values and reduction in staling, shrinkage and dough rising capacity, as shown in Tables 2 and 5. (Campagna et al. 2020) testified similar results. Density reflects the size and ratio of air cells to a solid product, bulk density is determined without the influence of compression, whereas true density excludes all pores. Bulk density was in the range of 1.65 and 2.5 g/cm^3, wherein lower bulk density values were found in RB with guar gum and VCOC with wheat bran fiber samples, which was found to be of better from the tested samples. True density values of samples ranged from 2.34 to 3.58 g/cm^3, and a higher range of values are desirable. The maximum values among the tested samples were found in the RB with wheat bran fiber and VCOC with wheat bran fiber incorporation. This corresponds to a better-quality product. This could be because wheat bran fiber is required to provide the dough with its structural structure. The current study's higher actual density and lower bulk density could be attributed to variables such as dilution of the protein matrix and enhanced dough viscosity because the gums and starch in the dough enhancers store more water. Another reason is that AO therapy can boost gluten strength and dietary fiber (lignin and hemicellulose) in the bran (Pandiselvam et al. 2018). The possible cause would be that AO treatment affects the potential production of disulfide bonds in the dough, which significantly impacts the dough system's viscoelastic stability and density attributes (Premjit et al. 2022). Lower density cutlery was lighter in weight and more flexible for transporting.

4.2. Structural characteristics of dough

X-Ray Diffraction analyses were performed to find the crystallinity and structural characteristics of the prepared dough samples reported in Figure 1. The results indicated a crystallinity between the range 30–45% for the tested dough samples, indicating the amorphous nature of the prepared dough. The results indicated a reduction in crystallinity index in the order of sample for RB without binder, followed by RB with starch, RB with wheat bran fiber, and RB with guar gum as binding agents. In contrast, for VCOC, the addition of binding agents improved the crystallinity index tremendously, particularly for samples added with guar gum. Full Width at Half Mean (FWHM) followed the same trend concerning crystallinity size since it is inversely proportional to the latter. The Crystallite size of the product was in the range of 0.49 to 0.90 nm; the maximum crystalline size was observed for VCOC, depicted in Figure 1 and Table 3. Crystallinity index and crystallinity size increased with combined UV and AO treatment compared to the control sample (19.8%) and were in line with the reports by (Dhandapani, Venugopal, and Vinoth Kumar 2019), whereas addition of binder resulted in a reduction in crystallinity of pretreated RB dough samples which might be attributed to formation of dense crystalline regions as a result of UV light treatment, which in turn affects the dough expansion ability, and AO has an oxidation effect that generates free radicals that attack the glycosidic bonds in starch and gums, with fibers leading to the destruction of the helical structure, thereby lowering the crystallinity index (Qiaoting et al. 2021). The addition of guar gum to VCOC increases V-type

Table 2. Physical characteristics of dough (RB: De-oiled Rice Bran; VCOC: Virgin Coconut Oil Cake).

Composition	Moisture content (%)	Dough rising capacity (%)	Bulk density (g/cm^3)	True density (g/cm^3)
C_{RB}	45±.0803	28	2.25 ± 0.01	2.68 ± 0.34
RB	45.20 ± 0.900	30	1.89 ± 0.06	2.34 ± 0.22
RB + Starch	45.20 ± 0.010	35	1.70 ± 0.31	2.51 ± 0.34
RB + Wheat bran fiber	45.20 ± 0.011	38	1.76 ± 0.42	2.63 ± 0.22*
RB + Guar gum	45.20 ± 0.012	42	1.65 ± 0.33*	2.42 ± 0.22
C_{VCOC}	45.5 ± 0.021	10	2.7 ± 0.21	3.58 ± 0.32*
VCOC	45.20 ± 0.013	10	2.38 ± 0.22	3.10 ± 0.22
VCOC + Starch	45.20 ± 0.140	17	2.42 ± 0.21	3.07 ± 0.11
VCOC + Wheat bran fiber	45.20 ± 0.150	18	2.21 ± 0.33*	3.29 ± 0.33
VCOC + Guar gum	45.20 ± 0.160	22	2.30 ± 0.44	2.91 ± 0.22

C_{RB} = Control Rice bran (UV and aqueous ozone treatment), C_{VCOC}= Control Virgin Coconut Oil Cake (UV and aqueous ozone treatment).

* 5% level of significance.

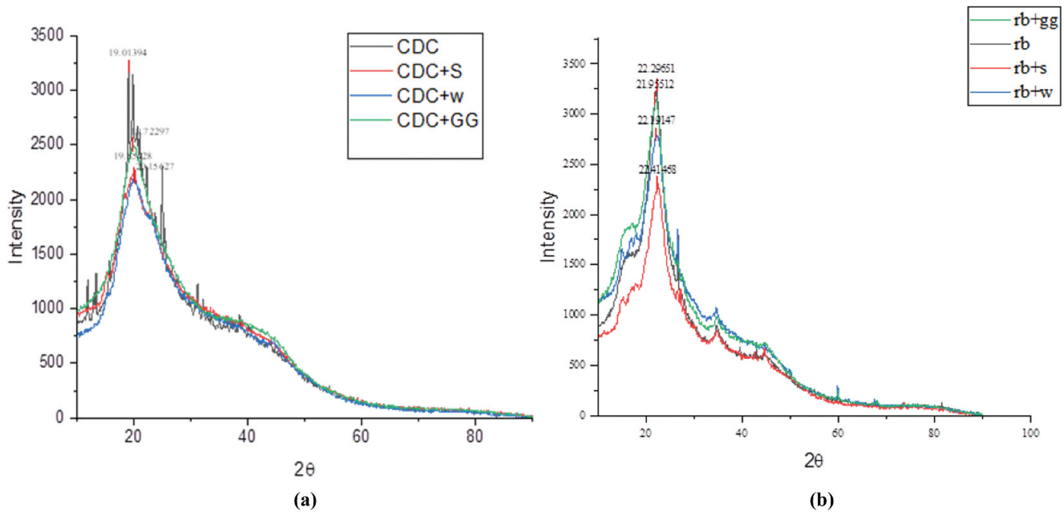


Figure 1. X-Ray diffraction graphs (a) Rice bran control vs Rice bran + Starch (b) Virgin Coconut De-Oiled Cake (VCDC) control vs Coconut De-oiled Cake (VCDC) control + Guar gum (control samples 19.8% reported by Dhandapani, Venugopal, and Vinoth Kumar 2019).

Table 3. Crystallinity index, Full Width at Half Mean (FWHM), and Crystallite size of the dough samples obtained through XRD analysis.

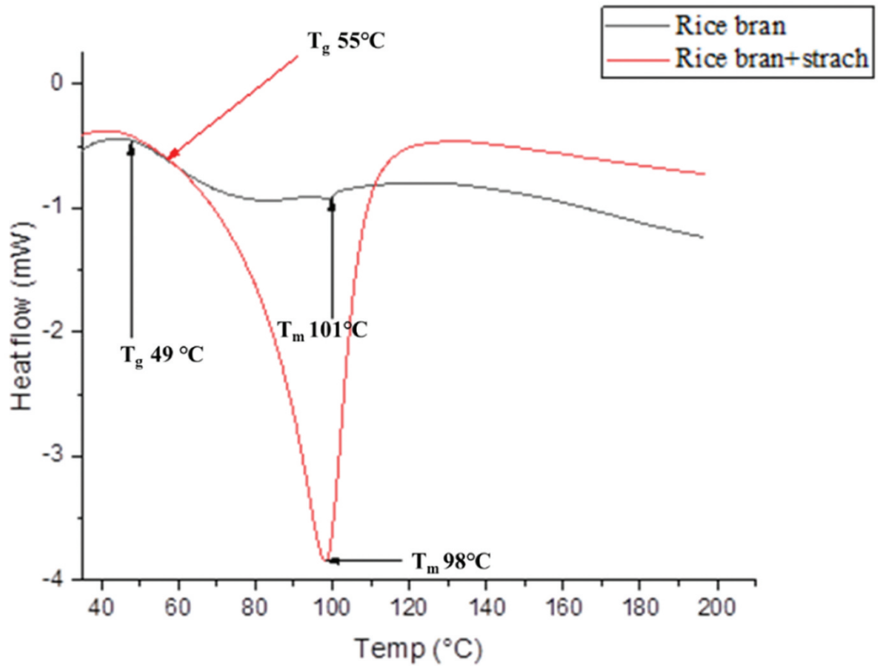
Composition	Crystallinity index (%)	FWHM (rad)	Crystallite size (nm)
RB	31.6602	0.1504	0.8944
RB + Starch	30.7740	0.2107	0.6388
RB + Wheat bran fiber	29.4301	0.2263	0.5945
RB + Guar gum	29.3701	0.2052	0.6454
VCOC	33.7444	0.1496	0.9039
VCOC + Starch	41.5843	0.2736	0.4934
VCOC + Wheat bran fiber	40.5025	0.2476	0.5454
VCOC + Guar gum	44.3540	0.2334	0.5787

RB: De-oiled Rice Bran; VCOC: Virgin Coconut Oil Cake), control samples 19.85% reported by Dhandapani, Venugopal, and Vinoth Kumar (2019).
* 5% level of significance

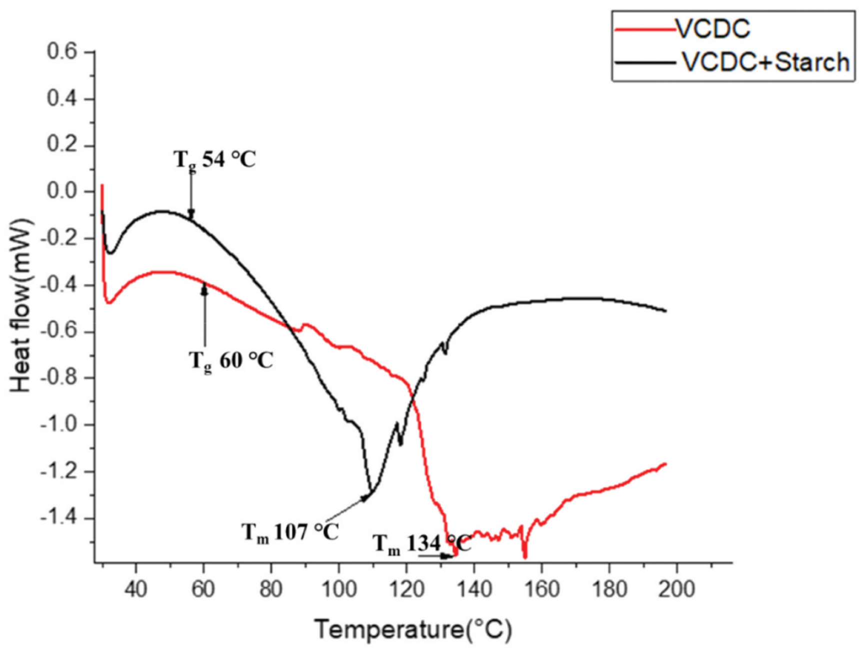
diffraction patterns due to the breaking down of the long chain to the short chain, leading to more alignment and a higher crystallinity index. In contrast, the decrease in crystallinity with wheat bran fiber and starch resulted in a softer texture of the dough and biodegradable cutlery (Mudgil 2018).

5. Differential scanning calorimetry

This technique was used to describe the changes related to dough components that may alter the macroscopic features observed, such as glass transition, gelatinization, and melting characteristics after exposure to UV and AO treatments. Figure 2 depicts that glass transition occurred for RB samples at 49°C and 55°C temperatures, while for VCOC samples, glass transition occurred at 54°C and 60°C respectively. The melting point of the samples occurred at 98°C and 101°C for RB samples, whereas 107°C and 134°C for VCOC samples. This could be due to amylopectin gelatinization; it may have shifted to a higher temperature as a result of the melting of residual amylopectin crystals (Shanakhat et al. 2019). The second peak, which occurs at temperatures ranging from 85.53 to 88.73°C for UV with AO-treated samples caused by the melting of amylose-fiber complexes, is determined by the microstructural characteristics of VCOC and RB. Because of the long-chain complex development of amylose-fiber compounds, which required a higher temperature to break,



(a)



(b)

Figure 2. Differential scanning calorimetry (a) Rice bran control vs. Rice bran + Starch (b) Virgin Coconut De-Oiled Cake (VCDC) control vs. Coconut De-Oiled Cake (VCDC) control + Guar gum.

the onset temperature of the Pure VCOC sample increased from 60°C to 134°C. Another conclusion evaluated from the graph is that the melting point significantly reduced with the addition of binding agents (fiber). (Bai and Zhou 2021) reported similar results that indicate a significant reduction of melting point mainly due to the changes in the degree of cross-linking of fiber with binders caused by the oxidation of AO during the mixing process. This could be beneficial for reducing process conditions, temperature and time for producing cutleries of desired quality.

5.1. Textural characteristics of dough

The textural properties of the prepared dough are tabulated in Table 4. Results on gumminess indicated higher gumminess for samples prepared with de-oiled RB as base material. The amount of energy required to chew semisolid food before ingesting it is called gumminess, indicating the dough's softness (Meng et al. 2021). Too much softness of dough is undesirable for cutlery production. The samples mixed with wheat bran fiber as a binding agent showed better results among the tested samples. UV with AO treatment enhanced disulfide bonding, glutenin polymer insolubility, and other potential cross-linking across wheat proteins with fiber (N. Li et al. 2018). Cohesiveness force samples with guar gum as a binding agent on RB and VCOC showed higher cohesiveness, which indicates better pressability to get the quality of the final product. Adhesiveness: UV with AO-treated RB and VCOC (without binder) exhibited lower adhesiveness. The adhesiveness of the RB with starch and wheat bran fiber addition and VCOC with starch and wheat bran fiber exhibits higher than the control sample. Higher cohesiveness and adhesiveness are most likely owing to the combined effect of AO and UV on the functional qualities of wheat flour's starch, protein, and other components (N. Li et al. 2018). The addition of a binder to the RB and VCOC increases hardness. Hardness was found to be higher for samples prepared with guar gum as binding material. The higher value of hardness indicates better binding properties, which might be explained why the oxidation of AO and radiation of UV promoted the cross-linking degree of proteins with fiber as well as gum (Bai and Zhou 2021). Guar gum exhibited better binding capacity among the tested. The dough produced using guar gum as binding material and RB as base material exhibited better properties. When adding guar gum to the mixture, including RB and VCOC, it can make a lattice with protein of base materials, thus preventing the breakdown of gas bubbles. The addition of guar gum competed for hydration with proteins, preventing the protein network from forming adequately. Due to the breakage of a weaker protein network, and stiffer or "heavy" dough mass on gas bubble expansion, the dough would not rise properly during UV with AO treatment (Yang et al. 2021). All the textural properties of dough significantly influence the crude fiber and the dietary fiber of raw materials.

Table 4. Textural characteristics of dough (RB: De-oiled Rice Bran; VCOC: Virgin Coconut De-Oiled Cake).

Composition	Average Gumminess (N)	Average cohesiveness	Average adhesiveness (J)	Average Adhesive Force (N)	Average hardness (N)
C_{RB}	20.0012 ± 0.05	1.78±.0001	−0.0005±.02	19 ± 0.05	12.3 ± 0.1
RB	19.8259 ± 0.27	1.6223 ± 0.010	− 0.0005 ± 0.01	18.8259 ± 0.25	12.2213 ± 0.90
RB + Starch	21.1546 ± 0.28	1.6654 ± 0.090	− 0.0002 ± 0.03	21.1546 ± 0.28	13.2374 ± 0.20
RB + Wheat bran fiber	18.4161 ± 0.25	1.7408 ± 0.028	− 0.0002 ± 0.01*	19.4270 ± 0.27	15.5626 ± 0.03
RB + Guar gum	21.8075 ± 0.23*	1.9289 ± 0.045*	− 0.0003 ± 0.06	21.8075 ± 0.23*	20.3621 ± 0.30*
C_{VCOC}	02.8713 ± 0.25	0.8928 ± 0.002*	−0.0026 ± 0.12	02.8902 ± 0.73	04.0021 ± 0.12
VCOC	02.7321 ± 0.26	0.7016 ± 0.036	− 0.0021 ± 0.07*	02.7321 ± 0.26	03.8941 ± 0.11
VCOC + Starch	03.0371 ± 0.32	0.6238 ± 0.024	− 0.0005 ± 0.07	03.0371 ± 0.32	04.8687 ± 0.24
VCOC + Wheat bran fiber	03.2087 ± 0.13	0.5697 ± 0.028	− 0.0004 ± 0.02	03.2087 ± 0.13	05.6314 ± 0.28
VCOC + Guar gum	05.9021 ± 0.25*	0.6058 ± 0.021	− 0.0096 ± 0.03	05.9021 ± 0.25*	09.7423 ± 0.18*

C_{RB} = Control Rice bran (UV and aqueous ozone treatment), C_{VCOC}= Control Virgin Coconut De-Oiled Cake (UV and aqueous ozone treatment.

5.2. Microbial characteristics of dough

The total plate count and total yeast count were carried out for all the tested samples. The results (Figure 3a,b) indicated similar trends in increment in yeast load/mold, estimated by the total yeast/mold count method. The initial bacterial load was lower, which might be attributed to the effectiveness of the pre-treatment process. UV treatment may have caused direct microorganism elimination by producing DNA denaturation (Jemni et al. 2014). Furthermore, the high oxidation potential of dissolved ozone inactivates bacteria by breaking their cellular membranes, resulting in cell lysis (Aslam, Shafiq Alam, and Pandiselvam 2021). The combined action of UV and ozonation in RB and VCOC has a substantial influence on the microbial load of the dough, especially in terms of lowering the total bacterial load. Since the dough prepared may not be stored for more than 24 hours, reducing microbial load using UV and ozonation can be considered an effective solution for the same.

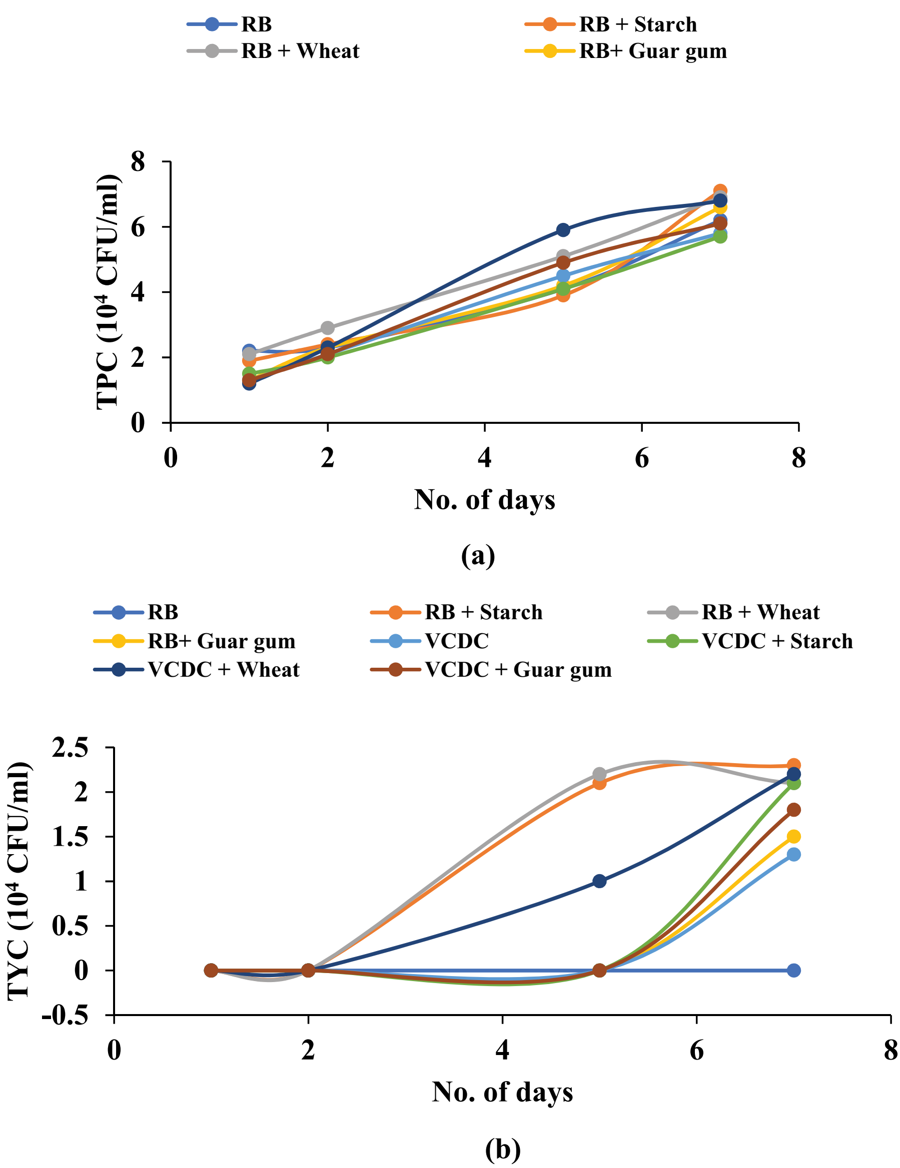


Figure 3. Microbial analysis of dough samples (a) Total plate count (b) Total yeast/mold count.

The prepared dough withstands bacterial contamination for up to 36 hours and fungal contamination for more than 48 hours, indicating the effectiveness of this combined pre-treatment on the dough, which could be preferred for biodegradable cutlery production. Therefore, it can be inferred that pre-treatment is vital for producing good quality dough since the produced dough is of good quality in terms of microbial content. The prepared dough was then used for the production of biodegradable cutlery.

5.3. Product characterization

Biodegradable plates were prepared using the tested dough (Figure 4), and the characteristics were calculated. The obtained values of tensile strength, water absorption capacity, moisture content and water activity are reported in Table 5. The results indicate that the tensile strength of samples improved with the increase of fiber in the raw material and with the addition of binder. Higher tensile strength is desirable for biodegradable products (Suderman, Isa, and Sarbon 2018). The tensile strength showed a similar range, with starch showing better tensile strength for RB and guar gum for VCOC. Moisture content values showed a similar range of values. All samples were in the acceptable range (below 14%). Finished cutlery samples exhibited water activity between 0.37 and 0.62, with lower water activity observed for samples with VCOC. Water absorption capacity is essential for determining the ability of cutlery to hold water, and lower values of water absorption capacity are desirable. For rice bran, starch as a binder showed lower water absorption capacity, whereas, for virgin coconut oil cake, guar gum exhibited lower water absorption capacity. Starch, along with RB, gave better combinations among the RB combinations, while guar gum showed better among plates prepared with VCOC. Starch, owing to its gelatinization properties (Yongfeng and Jane 2015) during heat treatment, provides better water absorption capacity to the product. Guar gum also has a good impact on water absorption capacity.

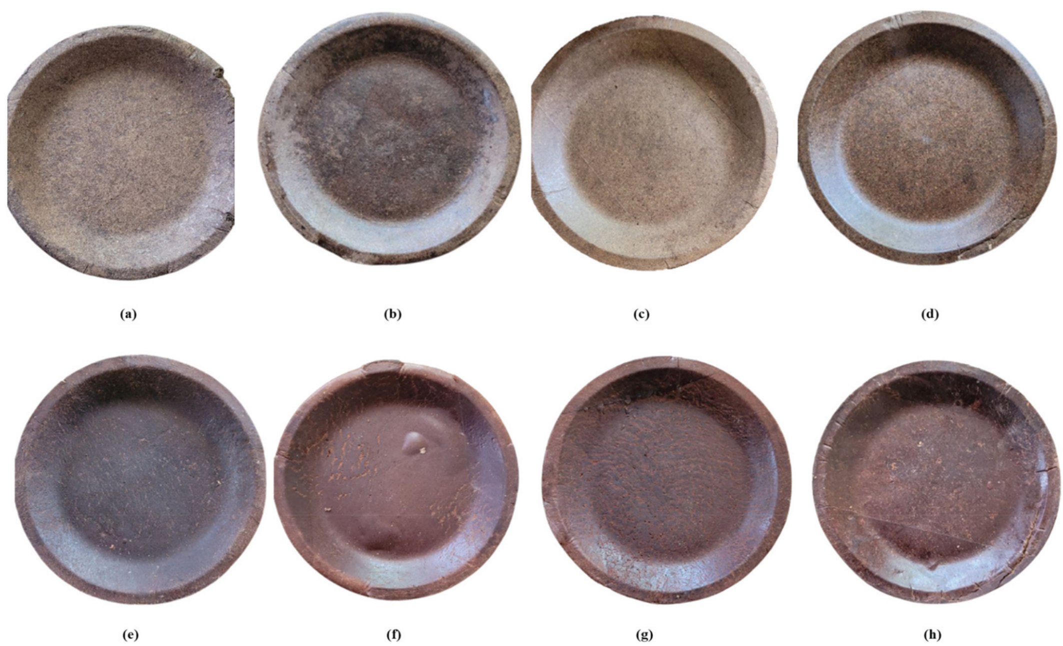


Figure 4. Finished biodegradable cutlery products (a) Rice bran (b) Rice bran + Wheat bran fiber(c) Rice bran + Starch (d) Rice bran + Guar gum (e) Virgin coconut oil cake (f) Virgin coconut oil cake + Wheat bran fiber(g) Virgin coconut oil cake + Starch (h) Virgin coconut oil cake + Guar gum.

Table 5. Analysis of properties of final cutlery product.

Composition	Tensile strength (MPa)	Moisture content (%)	Water activity	Water absorption capacity (ml/min)
RB	0.32 ± 0.013	12.90 ± 1.20	0.624 ± 0.003	3.18 ± 0.046
RB + Starch	0.58 ± 0.028	13.10 ± 1.10	0.565 ± 0.002	1.33 ± 0.014*
RB + Wheat bran fiber	0.62 ± 0.044*	12.50 ± 1.90	0.483 ± 0.006	2.02 ± 0.082
RB + Guar gum	0.57 ± 0.090	12.00 ± 0.63	0.374 ± 0.001	1.58 ± 0.016
VCOC	0.50 ± 0.064	11.11 ± 1.20	0.374 ± 0.005	2.46 ± 0.025
VCOC + Starch	0.56 ± 0.011	12.20 ± 0.90	0.526 ± 0.002	1.86 ± 0.038
VCOC + Wheat bran fiber	0.59 ± 0.041	12.29 ± 0.85	0.542 ± 0.003	2.36 ± 0.062
VCOC + Guar gum	0.61 ± 0.018*	12.30 ± 0.50	0.325 ± 0.002*	1.72 ± 0.052*

*lower water absorption, high tensile strength and low water activity indicates better properties of cutlery and long shelf life. (RB: De-oiled Rice Bran; VCOC: Virgin Coconut Oiled Cake) * 5% level of significance.

6. Conclusion

Biodegradable cutleries as an alternative to single-use plastics are of immense scope. Dough preparation is an important step in the production of cutleries. Analysis of the physical properties of flour in terms of moisture content and water activity was found in an acceptable range. Analysis of textural properties indicated better characteristics in terms of gumminess, hardness, adhesiveness, cohesiveness, and cohesive force for samples with guar gum as the binding agent, which could be attributed to better holding properties of guar gum. Structural analysis revealed the reduction in the melting point of the product in the presence of binding agents (fiber), which could be beneficial for temperature optimization of the process. XRD data indicated that the samples' crystallinity was in the range of 30–45%. Microbial analysis indicated a significant reduction in bacterial load and a considerable reduction in total yeast/mold count, which could be attributed to the effect of UV and ozonation pre-treatment on the flour. The tested dough yielded good quality plates, wherein starch as a binding agent showed better qualities among the samples tested with RB as the base material. In contrast, guar gum as a binding agent showed better qualities among the samples tested with VCOC as base material. This may be attributed to the gelatinization of starch during thermal processing, protein and dietary fiber interaction during mixing and the binding property of guar gum. From the results, it could be inferred that the production of biodegradable cutleries with an appropriate combination of base material (fiber enriched) and binding agent and pre-treatment procedures can effectively lead to the production of good quality biodegradable cutleries.

Highlights

- The natural fiber-based de-oiled rice bran (RB), virgin coconut oil cake (VCOC) and wheat bran used for preparation of biodegradable cutlery dough.
- To Enhance the shelf life (5.2 log microbial reduction) of dough treated with multiple non-thermal process (combined UV with aqueous ozone)
- The combined non-thermal processed dough improves the textural and structural properties as compared to untreated dough.
- The Glass transition (Tg) and melting temperature was high for VCOC dough compared to RB
- The VCOC and RB as a natural binder (due to fiber) substitute for synthetic polymers in making biodegradable cutleries

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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