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RESEARCH

Blending seaweed into bakery products

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Abstract

This study addressed the use of 2 g of *Ulva lactuca* and *Gracilaria corticata* in the preparation of bakery products (bread, cake, and cookies). The nutraceutical aspects of protein, carbohydrate, lipid and energy, mineral, and heavy metal contents, as well as microbial load, were analyzed.The protein content ranged from [9.38 ± 0.4 (Conventional Cake: CCa)-20.16 ± 0.5% (*Gracilaria corticata* Cookies: GcCo)]; meanwhile, the content ranges for the other nutrients were as follows: carbohydrate [39.5 ± 0.4 (Conventional Bread: CBr)-73.33 ± 0.4% (*Gracilaria corticata* Cake: GcCa)]; lipid [0.96 ± 0.04 (Conventional Bread: CBr)-22.98 ± 0.4% (*Gracilaria corticata* Cake: GcCa)], and energy [215.56 ± 0.4 (Conventional Bread: CBr)-535.32 ± 0.4 kcal (100 g)$^{-1}$ (*Gracilaria corticata* Cookies: GcCo)]. The results show that the products containing seaweed were comparatively better than the conventional products, in terms of both nutrition and shelf life (analyzed in terms of microbial load). Moreover, in most cases, the *G. corticata*-incorporated products had comparatively higher values than those made with *U. lactuca*. All the nutritional variables assessed in the present study were well within the permissible levels of The Food Safety and Standards Authority of India (FSSAI), and International Microbiological Standard (IMS). Furthermore, sensory analysis revealed the preference of these products for the average individual using a hedonic scale of 1–5. Statistical analyses of the palatability and acceptability of the products suggest the need for more seaweed bakery products with better nutritional benefits to the human body.

Keywords Bakery products · Human health · Nutraceutical analysis · Seaweeds · Sensory analysis

Introduction

The adverse impact of climate change has been witnessed in many parts of coastal India in forms such as sea level increases, cyclones, or erosion, and has seriously affected the economic profile of the area by creating environmental refugees (Kantamaneni et al. 2022). Therefore, to sustain the livelihood of poor communities the exploitation of marine and coastal resources is of utmost importance. As poverty-stricken people are more susceptible to adverse changes in climate change, boosting their livelihood standards and maintaining their nutrition level is one of the priorities of the present study. The focus of the present study is on developing cost-effective functional foods from coastal resources such as seaweeds, to incorporate them into the daily diet of those experiencing poverty to meet their nutritional deficiencies.

Bakery products (bread, cake, and cookies) are the most popular and versatile food for the poorest of the poor. This is because of their low cost, variability in taste, availability, and comparatively longer shelf life (Nagi et al. 2012). The bakery industry in India (especially in Maharashtra and West Bengal) is the largest food industry in India with an annual turnover of US$7.60 billion (2020),which is expected to grow to US$13.3 billion (2025) (Asmatoddin et al. 2008). The two major bakery industries (bread and cookies) account for almost 81% of the bakery products. Cakes are among the baked products that have gained popularity in recent times because of their "ready-to-eat" convenience, reasonably good shelf life, and the fact that they can be consumed by persons of all ages. The consumption of bakery products has accelerated to nearly 55%, not only in rural areas but also in urban areas (Asmatoddin et al. 2008). India is the second largest producer of biscuits after the USA and has traditionally been an unorganized sector, contributing to 70% of the total bakery production. Although bakery products

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have been considered as "a sick man's diet," they have now become a functionally essential food for the vast majority of the global population. In the present study, emphasis has been placed on the production of bakery products from green (*Ulva lactuca*) and red (*Gracilaria corticata*) seaweeds to create value-added products in the form of conventional baked goods.

Seaweeds are a protein source as they contain all nine essential amino acids (histidine, methionine, leucine, isoleucine, tryptophan, lysine, phenylalanine, threonine, and valine) required by the human body. These help in protein synthesis, tissue repair, and nutrient absorption in the body (Collins et al. 2016). Seaweeds are also known as low-calorie food because of their low lipid content (0.5–4.5% dw) (Schmid et al. 2018). Seaweeds are also rich in fatty acids but the lipid content is generally low (Narayan et al. 2008). Approximately 74% of the lipids in marine algae are composed of ω-3 and ω-6 polyunsaturated fatty acids (PUFAs) (Debbarma et al. 2016; Lorenzo et al. 2017). Green algae (*U. lactuca*) generally contain a high amount of linoleic acid (C18:2ω6), whereas red algae (*G. corticata*) contain eicosapentaenoic acid (C20:5ω3), with values of 16.7% and 13%, respectively (Pereira et al. 2012). The carbohydrates in seaweeds represent 50% of their photosynthetic reserves which include sugars, starches, and fibers (Rioux and Turgeon 2015). However, many of the seaweed carbohydrates are not digested by humans (e.g. agar, carrageenan, ulvan etc.) but after different hydrothermal treatments (such as boiling and cooking) the digestibility is enhanced by nearly four times (Fleurence 2016; Garcia-Vaquero and Hayes 2016; Batista et al. 2020; Juul et al. 2022; Pudlo et al. 2022). Carbohydrates are the main energy source in the human body. Furthermore, the presence of carbohydrates prevents the use of protein and enables fat metabolism. Seaweed products can be regarded as "functional foods" owing to their benefits to the human body in providing a balanced nutrition, thereby improving health and wellbeing (Ross 2000). It is well documented that seaweeds have a very high nutraceutical potential, and have been proven to be a good source of dietary fiber, protein, antioxidants, carotenoids, and many important minerals (Hayes 2015; Ganesan et al. 2019; Shannon and Abu-Ghannam 2019; Peñalver et al. 2020). Furthermore, certain components like dietary fiber (Peñalver et al. 2020), fucoxanthin (Peng et al. 2011) and carotenoids like astaxanthin (Banerjee et al. 2009; Ghosh et al. 2011; Peng et al. 2011)) in marine foods have well-defined physiological effects on human health (Kadam and Prabhasankar 2010) without changing the sensory properties of food. Manufacturing new products by adding or modifying persistent products and bringing out new functional natural products to consumers is a real challenge for manufacturers (Urala and Lähteenmäki 2004). Moreover, consumer awareness of the use of natural marine products to provide health benefits at the grassroots level is a present need (Bizzaro et al. 2022; FAO 2022). There is much interest in seaweed hydrocolloids in human nutrition as they provide dietary fiber and phytochemicals, among many other nutrients that have been recognized as "beneficial" in the healthcare system (Li and Nie 2016). Recent advances in the research on the biochemical constitution of seaweed and its incorporation into various products, such as pasta, bread, cake, cookies, curd, and ice cream, have boosted the number of functional food ingredients for future diets (Mitra 2016; Nova et al. 2020). It is also expected that such products will help to mitigate health problems in humans. Recently the European Commission of the European Union has designated *Fucus vesiculosus*, an edible brown seaweed, as a "novel food" for human consumption (Arufe et al. 2018). The incorporation of these brown algae into traditional wheat bread improved the nutritional properties of traditional foods (Poutanen et al. 2014). Studies have also reported that high-quality bakery products can be created by the incorporation of seaweed to improve the uniform crumb structure, shelf life, and maintain, while reducing staling (Mamat et al. 2014). The addition of green, brown and red seaweeds to bakery products, and the subsequent evaluation of these products, has been evaluated (Cofrades et al. 2008; Moroney et al. 2015—pork products – *Laminaria digitata, Himanthalia elongata*, *Undaria pinnatifida*, *Porphyra umbilicalis*; Cofrades et al. 2011—chicken products—*H. elongata*; Cox and Abu-Ghannam 2013a—beef products—*H. elongata*; Lee et al. 2010, Cox and Abu-Ghannam 2013b, Fitzgerald et al. 2014, Mamat et al. 2014—bread – *Palmaria palmata*, *Kappaphycus alvarezii*, *H. elongata*, *Myagropsis myagroides*; Chang and Wu 2008 and Chang et al. 2011—noodles – *Monostroma nitidum*; Prabhasankar et al. 2009—pasta—*U. pinnatifida*; O'Sullivan et al. 2014—milk –*A. nodosum*, *F. vesiculosus*; Mamatha et al. 2007 – Pakoda – *Ulva*). These products have been evaluated with respect to nutrient composition, calorific value, technological and sensory evaluation, and consumer acceptability (Różyło et al. 2017).

Surveys have revealed that baked products are the most consumed food worldwide, which is helpful in delivery (Kadam and Prabhasankar 2010).It has also been reported that the nutritional and health benefits in bread increase with the addition of folic acid, skim milk powder, and soya proteins (Crider et al. 2011). Bakery products made with seaweed have been regarded as a phytomedicinal or botanical product, which has been tested in proliferation and radical scavenging analyses and found to be safe for human consumption. Hence, the notion that "Food is thy Medicine" has been raised to increase the ability to combat diseases and promote well-being (Priya et al. 2017).

In this context, the objective of the present study was to assess seaweed (*U. lactuca* and *G. corticata*) and their products (bread, cake, and cookies) in terms of protein,

carbohydrate, lipid, mineral (nutritional), and heavy metal contents as well as their microbial load (anti-nutritional). We also sought to evaluate their palatability and quality based on survey analysis.

Materials and methods

Seaweed collection

In November fresh edible seaweed samples (*Ulva lactuca* and *Gracilaria corticata*) were collected from the shores of Tenneti Park (Lat 17°44′50.207" N, Long 83°20′59.2434" E) in the Visakhapatnam coast of Andhra Pradesh in India. The sampled species were identified as per the standard taxonomic keys (Rao and Sreeramulu 1964). The samples were thoroughly washed with seawater, packed in an icebox and transferred to the laboratory. In the laboratory the seaweeds were thoroughly cleaned with distilled water, had their epiphytes and holdfasts removed, and dried in a hot air oven at 40 °C for 24 h. The seaweed was then powdered with the help of a mixer grinder (Bajaj-750 classic mixture grinder, Mumbai, Maharashtra, India). The dried seaweed powder was then stored in an airtight poly pack at 4 °C for subsequent use in the additional experiments.

Formulation of blends into bakery products

According to Prabhasankar et al. (2009), Lee et al. (2010), Mamat et al. (2014), Mitra et al. (2016), and others, the addition of 2 g of seaweed yielded a positive significant value (increased the crispiness of the biscuit and softness of bread, lower the microbial growth, improved the binding and nutritional properties)in comparison to the values of the other formulations. Hence, 2 g of *U. lactuca* and *G. corticata* powder were incorporated into bread, cake, and cookies with ingredients such as whole wheat flour (Aashirvaad), white flour (Ahaar), salt (Tata), sugar (Trust), yeast (Gloripan), commercial water, baking powder (Weikfield), baking soda (Weikfield), milk (Omfed), sunflower oil (Fortune), vanilla essence (Symega), and butter (Amul).These were purchased from local market of Koraput district in Odisha (Table 1).

Bakery product preparation

Bread preparation

The bread was prepared according to the standard procedure described by Adeniji (2013).The dough mixture was composed by substituting whole wheat flour with 0 g or 2 g of seaweed powder (*U. lactuca* and *G. corticata*). The 0 g seaweed powder served as a control. Bread was prepared by adding whole wheat flour(100 g), salt (1 g), powdered

Table 1 Formulation for the preparation of bread, cake and cookies

Ingredients	CBr	UlBr	GcBr	CCa	UlCa	GcCa	CCo	UlCo	GcCo
Whole Wheat flour (g)	100	100	100	-	-	-	100	100	100
White flour (g)	-	-	-	100	100	100	-	-	-
Salt (g)	1	1	1	-	-	-	-	-	-
Powdered sugar (g)	2	2	2	80	80	80	50	50	50
Yeast (g)	2	2	2	-	-	-	-	-	-
Commercial water (mL)	70	75	73	-	-	-	-	-	-
Baking powder (g)	-	-	-	1.3	1.3	1.3	0.5	0.5	0.5
Baking soda (g)	-	-	-	1.3	1.3	1.3	-	-	-
Skim milk (mL)	-	-	-	100	100	100	40	40	40
Sunflower oil (mL)	-	-	-	60	60	60			
Vanilla Essence (mL)	-	-	-	0.3	0.3	0.3	-	-	-
Butter (mL)	-	-	-	-	-	-	50	50	50
Ulva lactuca powder (g)	-	2	-	-	2	-	-	2	-
Gracilaria corticata powder (g)	-	-	2	-	-	2	-	-	2
Fermentation	1½ h at 32–35 °C	1½ h at 32–35 °C	1½ h at 32–35 °C	-	-	-	-	-	-
Proofing	1½ h at 32–35 °C	1½ h at 32–35 °C	1½ h at 32- 35 °C	-	-	-	-	-	-
Baking temperature (°C)	220	220	220	180	180	180	160	160	160
Duration (min)	20	20	20	20	20	20	20	20	20

CBr Conventional Bread, *UlBr Ulva lactuca* Bread, *GcBr Gracilaria corticata* Bread, *CCa* Conventional Cake, *UlCa Ulva lactuca* Cake, *GcCa Gracilaria corticata* Cake, *CCo* Conventional Cookies, *UlCo Ulva lactuca* Cookies, *GcCo Gracilaria corticata* Cookies

sugar (2 g), dry yeast (2 g), mineral water (70 mL), and seaweed powder (2 g). The ingredients were optimally mixed and fermented for 1.5 h at 32–35 °C. The dough was then punched and kneaded to release the extra air and molded to a suitable shape. It was then placed in a bread tin container (6.35 × 8.33 × 5.08 cm) and left for 1.5 h at 32–35 °C for proofing. The bread was baked in a microwave oven [IFB 23 L Convection Microwave Oven (23SC3, Silver), India] at 220 °C for 20 min, yielding three batches of bread. The Conventional Bread is represented as CBr, *U. lactuca* bread as UlBr, and *G. corticata* bread as GcBr] (Table 1). The baked loaves were then cooled for 2 h before further analysis.

Cake preparation

The method of Seth and Kochhar (2018) was adopted for cake preparation, with some modifications by reducing the amount of sugar, which is favorable for diabetic patients. Cake batter of a soft and smooth consistency was prepared with the addition of white flour (100 g), powdered sugar (80 g), baking powder (1.3 g), baking soda (1.3 g), skim milk (100 mL), sunflower oil (60 mL), vanilla essence (0.3 mL), and seaweed powder (*U. lactuca* and *G. corticata*) (2 g) in an electric mixer (Bajaj Classic 750 Mixer Grinder, India). The batter without seaweed powder was referred to as the control. The smooth cake batter was placed in an oil-greased pan (10 cm × 5.1 cm) and baked in a microwave oven [IFB 23 L Convection Microwave Oven (23SC3, Silver, India)] at 180 °C for 20 min, yielding three batches of cake. The Conventional Cake is represented as CCa, *U. lactuca* cake as UlCa, and *G. corticata* cake as GcCa. These were then cooled for 1 h at ambient temperature for further analysis (Table 1).

Cookie preparation

Cookies were prepared according to the procedure of Ceserani et al. (2004). The dough was composed of whole wheat flour (100 g), powdered sugar (50 g), baking powder (0.5 g), skim milk (40 mL), butter (50 mL), and seaweed powder (*U. lactuca* and *G. corticata*) (2 g). Dough made without seaweed powder was used as control. All ingredients were mixed to prepare a hard dough from which 1 tablespoon of dough was shaped to make cookies. The dollops of dough were then placed in an oil-greased pan and baked in a microwave oven [IFB 23 L Convection Microwave Oven (23SC3, Silver, India)] at 160 °C for 20 min, yielding three batches of cookies. The Conventional Cookies are represented as CCo, *U. lactuca* cookies as UlCo, and *G. corticata* cookies as GcCo. All cookies were cooled and packed in polyethylene for further analysis (Table 1).

Biochemical analysis of seaweed bakery products

Protein analysis

Protein content was evaluated using the standard method (Lowry et al. 1951). 0.1 g of dried powdered sample was homogenized in a porcelain mortar and pestle with 5 mL Na_3PO_4 (pH 7.0) and one pinch of D-sorbitol for a finer paste. This mixture was then centrifuged at 12,298 rcf for 15 min. To that 0.1 mL of sample extract with 0.9 mL distilled water, 4 mL Reagent-C [(Reagent-A: NaOH (0.4 g) + Na_2CO_3 (2 g) + distilled water (50 mL); Reagent-B: $CuSO_4$ (0.5 g) + $KNaC_4H_4O_6 4H_2O$ (1 g) + distilled water (50 mL); Reagent-C = Reagent-A (50): Reagent-B (1)] was added. It was then incubated for 10 min at ambient temperature. This was followed by the addition of 0.5 mL Folin–Ciocalteu reagent, and the resulting mixture was again incubated for 10 min. The results were recorded at 660 nm absorbance. The values were expressed as mg g^{-1}dw using bovine serum albumin as the standard.

Carbohydrate analysis

The carbohydrate content was estimated using the method of Sadasivam and Manickam (2007). A 0.5 g portion of powdered sample was homogenized in a porcelain mortar and pestle with 10 mL methanol (80%), and centrifuged at 1792 rcf for 20 min. The extract was then transferred to a water bath until the extract volume reached 4 mL (after the alcohol evaporated). The remaining extract was adjusted with methanol in a 25 mL Erlenmeyer flask. To 0.2 mL of the sample extract, 0.8 mL distilled water and 4 mL anthrone reagent were added [(anthrone (0.2 g) + H_2SO_4 (100 mL)]. Distilled water (1 mL) and anthrone reagent (4 mL) were added to the blank instead of the sample and placed in ice water. It was then transferred to a water bath for a few minutes, and a reading was taken after cooling at 630 nm. The value was expressed as mg g^{-1}dw using glucose as the standard.

Lipid analysis

Lipid (solvent extraction) content was determined using the Association of Official Analytical Collaboration (AOAC 2012) method. The initial weight of the beaker was measured, and then 100 mL of petroleum ether was added to 2 g of powdered sample in a thimble. It was dipped in a beaker and placed in a Soxhlet extractor for 3 h (SOCS PLUS SCS-03E; Pelican Equipment, India). After cooling the beaker to ambient temperature, the lipid content was calculated by subtracting the final weight from the initial weight.

Energy value analysis

The caloric content was estimated according to the guidelines of the National Research Council (NRC) (1989) using the following equation:

$$\text{Energy value } \left(\text{kcal}(100\text{g})^{-1}\right) = 4 \times \text{protein}(\%) + 9 \times \text{lipid}(\%) + 4 \times \text{carbohydrate}(\%)$$

Analysis of mineral and heavy metal contents

Acid digestion

One gram of each seaweed powder sample was placed in an Erlenmeyer flask to which 20 mL of concentrated HNO_3 was added. The mixture was left to rest for 28 h at room temperature (37 °C). The flask was then placed on a hot plate at 120 °C to boil and vaporized. The dry residue in the Erlenmeyer flask was again left to rest for 18 h at room temperature. The diacid composition was a ratio of 9:4 of nitric and perchloric acid to each sample for cold digestion, and again, the acidified sample was boiled at 120 °C and vaporized. After a few hours, the cooled samples were reacted with 20 mL of 10% HNO_3 and filtered through Whatman No.42 filter paper. The extract was collected in a 25 mL Erlenmeyer flask, and the volume was adjusted with distilled water. The acid digested samples were analyzed using a flame photometer (SYSTRONICS Model (Type:128)μ Controller-Based Flame Photometer; India) and Inductively Coupled Plasma Atomic Emission (Perkin Elmer Optima 7300DV; India).

The mineral (K and Na) concentrations of the samples were analyzed using the methodology described in 956.01, and Ca was analyzed as stated by Protocol: P05-011A AOAC (2012). The digested extract that was collected was made to the appropriate target and aspirated into a flame photometric analyzer (SYSTRONICS Model (Type:128) μ Controller-Based Flame Photometer). A standard curve was then plotted for analytical-grade KCl (HiMedia), NaCl (HiMedia), and calcium concentrations. The Cl content was analyzed as described in the IS 7224:2006 method, whereas Mg, Fe, Mn, Cr, Hg, As, Cd, Pb, and Ni were analyzed using inductively coupled plasma optical emission spectrometry(ICP-OES) (Commgrade/L3-HYB-FOO-023) following acid digestion. The Cu and Zn contents were determined using ICP-OES following wet oxidation. The reported results were compared with the Food Safety and Standards Authority of India (FSSAI).

Microbial profile analysis

Total plate count: Heterotrophic plate count method, 9215 (APHA 2017)

Plate count agar (tryptone glucose yeast agar) was used along with the pour plate method (Sect. 9215B). The medium was inoculated with a variety of microbial enzymes and incubated at 35 °C for 48 h, which produces 4-methylumbelliferone in 48 h at 35 °C. Thereafter the 4-methylumbelliferone fluorescence was exposed to ultraviolet light at a wave length of 365–366 nm. The colonies on the plates were counted, yielding 30–300 colonies, and expressed in CFU mL^{-1}.

$$\text{CFU } (100 \text{ mL})^{-1} = \frac{\text{Colonies counted}}{\text{actual volume of sample plated (mL)}}$$

Total coliform and *Escherichia coli*: Dual-chromogen membrane filter in m-ColiBlue24 medium using the 9221B, E method (APHA 2017)

Both the total coliform and *E. coli* concentrations were detected and simultaneously calculated in water, diluted seaweed, and bakery products using this membrane filter medium, depending on their specific enzyme activities. The coliform bacteria were identified as they appeared as red colonies when m-ColiBlue24 broth plates were incubated at 35 °C for 24 h in the presence of lactose and a nonselective dye [2,3,5-triphenyltetrazolium chloride (TTC)]. At the same time, with the action of ß-glucuronidase enzyme on 5-bromo-4-chloro-3-indolyl-ß-Dglucuronide (BCIG), blue/purple colonies were produced, which distinguished *E. coli* from the other coliform bacteria in the same medium.

Calculation of total coliform and *E. coli* densities were done according to the following formula:

$$\text{TC } (100 \text{ mL})^{-1} = \frac{\text{number of red and blue purple colonies}}{\text{volume of sample filtered (mL)}} \times 100$$

$$E.coli \text{ } (100 \text{ mL})^{-1} = \frac{\text{number of blue–purple colonies}}{\text{volume of sample filtered (mL)}} \times 100$$

Bacterial organism analysis using the 9260 (APHA) method (2017)

Vibrio cholera and *Vibrio parahaemolyticus* were cultured on plate medium with Thiosulfate-Citrate-Bile Salts-Sucrose agar and incubated for 6–8 h at 36 °C. *Salmonella typhi* and *Shigella dysenteriae* were identified in diluted samples using Deoxycholate Citrate Agar medium with non-lactose fermenters, and incubated for 18–24 h at 35 °C. This produced adequately separated colorless colonies with large *S. typhi* and small *S. dysenteriae*, which were counted and calculated to determine their population. For *Staphylococcus aureus*, the two-plate procedure was used, featuring the membrane filter technique to culture and identify *S. aureus* in the selected samples. Membrane filters were placed on R2A agar (Sect. 9215A.6*c*) and incubated for 24 h at 37 °C. The medium then presented slate-gray to jet-black colony formations as indicators of the presence of this microbe.

Determination of bakery product quality

Physical analysis

The weights (g) of the dough and batter before and after baking were measured using an electronic digital kitchen weighing scale. The specific gravity of the batter was measured using the AACC method (1983) by dividing the mass of the batter volume by the mass of an equal volume of water. The volume (cm^3) of bread and cake was calculated using method 10–05.01 mentioned in AACC (2000a, b), with grain displacement obtained by subtracting the volume of rice grain in the vacant container from the volume of rice grain with the sample in the container. The volume (cm^3) of cookies was calculated according to the equation of Jemziya and Mahendran (2017) by multiplying the area of the cookies by their thickness.

$$\text{Volume (cm)}^3 = \frac{HD^2}{4}$$

where: H = thickness of cookie (cm) and D = diameter of cookie (cm)

The specific volume ($cm^3\ g^{-1}$) of the products was estimated by dividing its volume by its weight to measure the density ($g\ cm^{-3}$), which was then divided by its volume (2000). Using a Vernier caliper (125 mm) the diameter (cm), height (cm), and thickness (cm) of the bread slices, cakes, and cookies were measured. The spread ratio of the cake and cookies was evaluated by dividing their diameter by their thickness or height. The weight loss (%) of the products was analyzed using the following equation:

$$\text{Weight loss (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

where: W_1 = weight of dough or batter and W_2 = weight after baking (Rodríguez-García et al. 2013).

Texture analysis

Texture analysis [(hardness (N), adhesiveness (Ns), springiness (mm), cohesiveness, gumminess (N), and chewiness (mg)] of the products were independently measured by the 74–09 method (AACC 2000a; b) using a texture analyzer

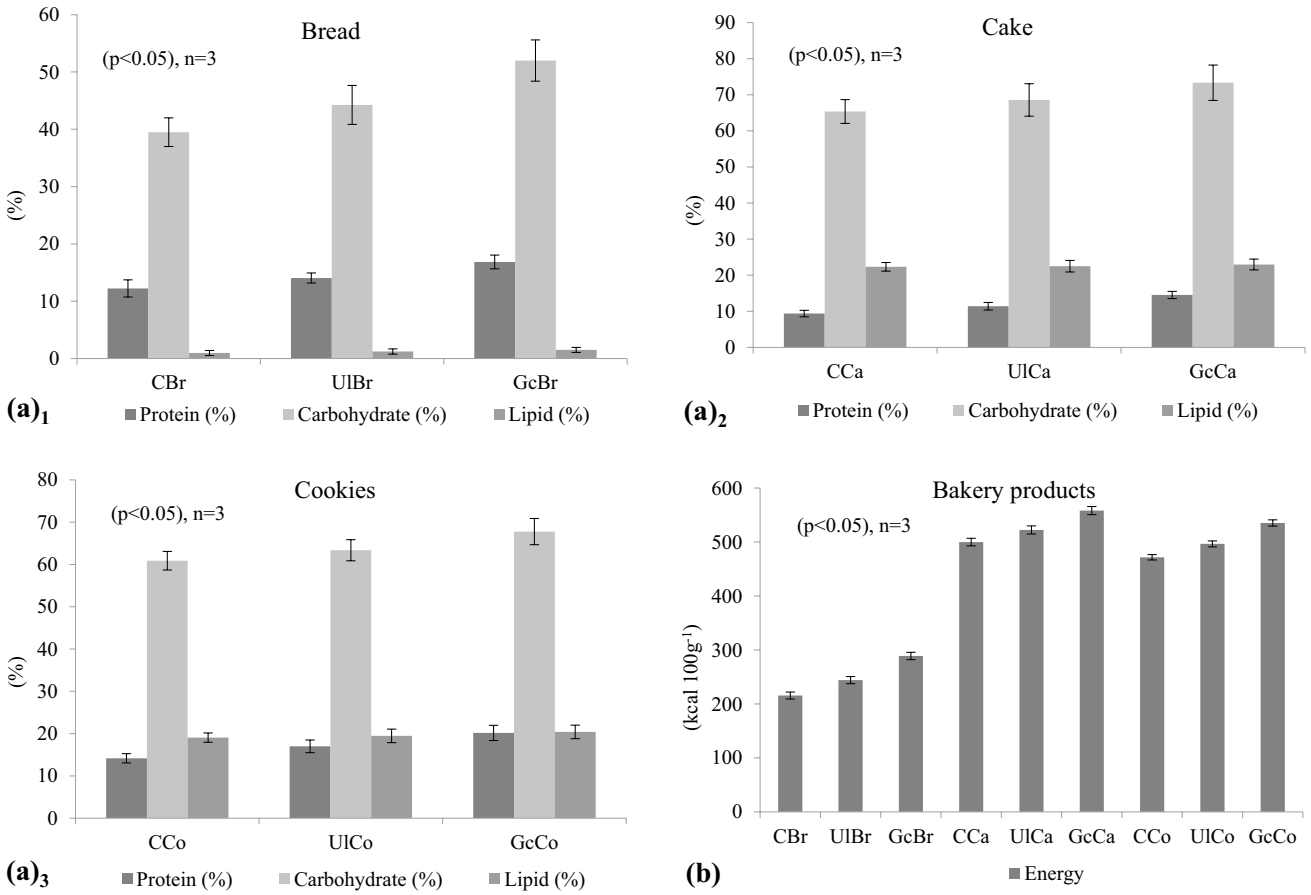

Fig. 1 (a_1-c_3) Biochemical parameters (a_1: bread, a_2: cake, a_3: cookies), caloric content-energy (b: bakery products) and mineral content (c_1: bread, c_2: cake, c_3: cookies) of conventional and seaweed bakery products

(CT3, Food Texture Analyzer; India). Bread and cake samples were cut from the middle (2 × 2 × 2 cm) and placed beneath the cylindrical probe (P/75). It was then compressed, with a 5 kg load up to 45% compression of its original height, at a speed of 1 mm s^{-1} with a 5 s interval between the two compressions. In the case of cookies, a 50 kg load was applied and moved downward until the cookies broke (Mamat et al. 2010). The data are reported from the curve obtained using the texture analyzer software.

Color analysis

The color of the bread (crust and crumb), cake, and cookie samples was independently evaluated in triplicate and analyzed using a colorimeter (Lab Junction, LJ-312, India), as per the CIELAB value [(L^* lightness (0: dark to 100: light), a^*redness (> 0: red to < 0: green),and b^* yellowness (> 0: yellow to < 0: blue)]. The total color difference ($\Delta E.^*$) was calculated using the following equation (Arufe et al. 2018):

$$\Delta E^* = \sqrt{\left(L_r^* - L_i^*\right)^2 + \left(a_r^* - a_i^*\right)^2 + \left(b_r^* - b_i^*\right)^2}$$

where: L_r^*, a_r^*, b_r^* are the color characteristics of conventional products and L_i^*, a_i^*, b_i^* are the color characteristics of the seaweed-added bakery products. The levels of color distinctions were classified as either very distinct ($\Delta E^* < 3.0$), distinct ($1.5 < \Delta E^*$),or less distinct ($\Delta E^* < 1.5$).

Sensory evaluation

The sensory properties of the bread, cake, and cookies were evaluated using 52 panelists (Larmond 1977). These were people familiar with these products, including research scholars, PG students, and staff (male and female) aged 20–60 years old from the Central University of Odisha, Koraput. Among them ten members were trained panelists (staff and research scholar), thirty members were semi-trained panelists (PG students) and twelve members were the consumer panelists (neighbors). Entire slices of bread (25 g), cubed pieces of cake (23 g), and one piece of cookie (21 g)were given to the panelists for sensory analysis. The samples were randomised for the panellists (Indicated with numbers i.e. CBr: 110, UlBr: 120,GcBr: 130, CCa: 210, UlCa: 220,GcCa: 230, CCo: 130, UlCo: 230, GcCo: 330)

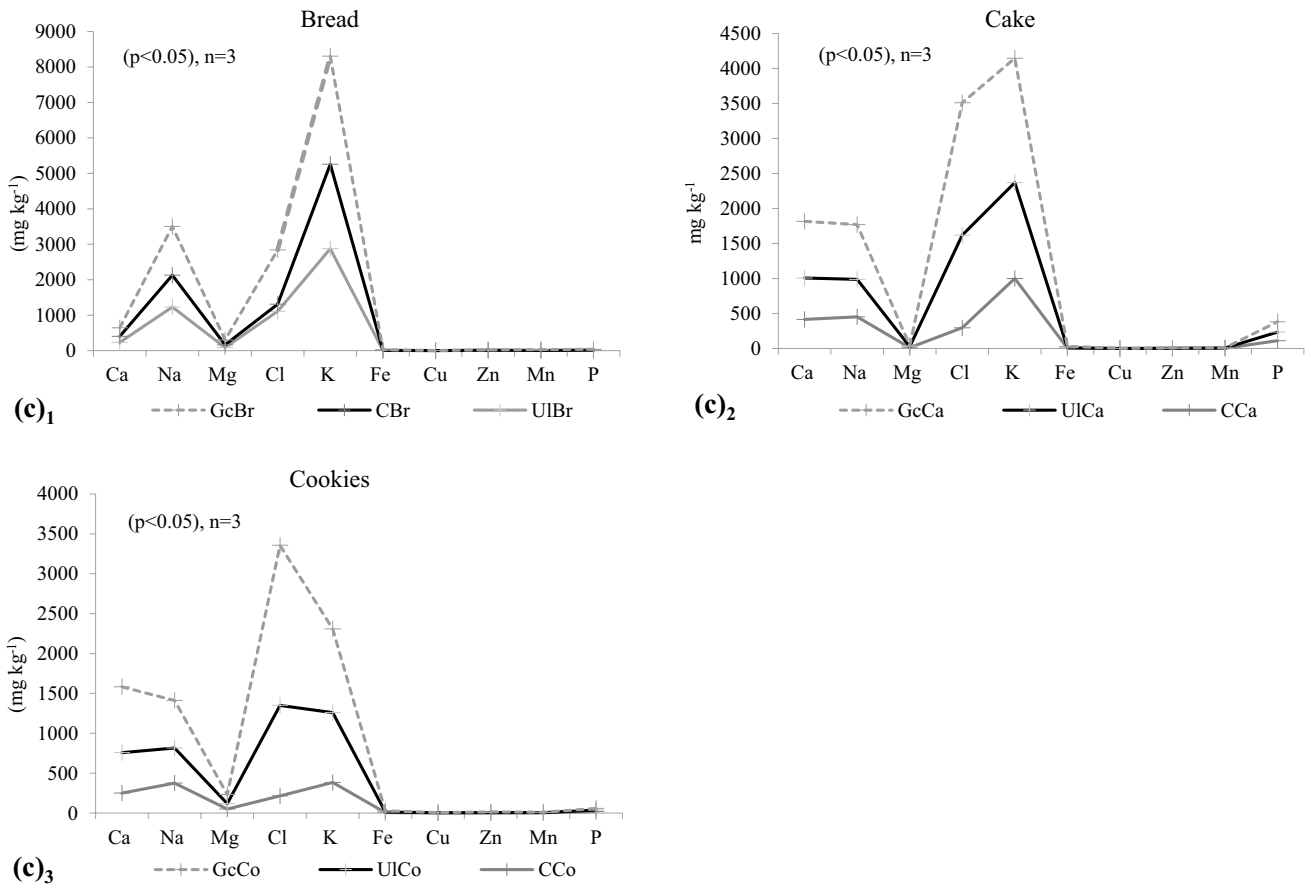

Fig. 1 (continued)

Table 2 Duncan's posthoc analysis to show variation between the nutraceutical properties of seaweeds and their bakery properties

		CBr	UlBr	GcBr	CCa	UlCa	GcCa	CCo	UlCo	GcCo	FSSAI
Biochemical parameters (%)	Protein	12.23 ± 0.4^{c}	14.05 ± 0.5^{d}	16.85 ± 0.4^{e}	9.38 ± 0.4^{a}	11.41 ± 0.4^{b}	14.53 ± 0.4^{d}	14.16 ± 0.4^{d}	16.99 ± 0.4^{e}	20.16 ± 0.5^{f}	60 g d^{-1*}
	Carbohydrate	39.5 ± 0.4^{a}	44.25 ± 0.4^{b}	52.00 ± 0.4^{c}	65.35 ± 0.5^{f}	68.56 ± 0.5^{h}	73.33 ± 0.4^{i}	60.88 ± 0.5^{d}	63.36 ± 0.4^{e}	67.77 ± 0.4^{g}	257–264 g d^{-1**}
	Lipid	0.96 ± 0.04^{a}	1.22 ± 0.4^{a}	1.5 ± 0.5^{a}	22.33 ± 0.5^{d}	$22.5 \pm .4^{d}$	22.98 ± 0.4^{d}	19.06 ± 0.4^{b}	19.46 ± 0.5^{b}	20.40 ± 0.5^{c}	57.1–47.9 g d^{-1**}
Energy (kcal $(100g)^{-1}$)	Energy	215.56 ± 0.4^{a}	244.18 ± 0.4^{b}	288.9 ± 0.5^{c}	499.89 ± 0.51^{f}	522.38 ± 0.4^{g}	558.26 ± 0.4^{i}	471.7 ± 0.4^{d}	496.54 ± 0.4^{e}	535.32 ± 0.4^{h}	2730 kcal d^{-1**}
Minerals (mg kg^{-1})	Ca	169 ± 0.5^{a}	$233 \pm .4^{b}$	243 ± 0.5^{c}	415 ± 0.4^{e}	$592 \pm .4^{h}$	808 ± 0.4^{f}	250 ± 0.5^{d}	507 ± 0.5^{g}	825 ± 0.4^{i}	800 mg d^{-1**}
	Na	897 ± 0.4^{g}	1232 ± 0.5^{h}	1373 ± 0.5^{i}	452 ± 0.4^{c}	536 ± 0.5^{e}	782 ± 0.4^{d}	375 ± 0.4^{a}	440 ± 0.5^{b}	596 ± 0.5^{f}	2100 mg d^{-1**}
	Mg	78 ± 0.4^{d}	86 ± 0.4^{e}	138 ± 0.5^{g}	11.5 ± 0.4^{a}	13.4 ± 0.5^{a}	17.5 ± 0.5^{i}	49.9 ± 0.4^{b}	67.8 ± 0.4^{c}	113 ± 0.5^{f}	340 mg d^{-1**}
	Cl	199 ± 0.5^{a}	1110 ± 0.4^{d}	1533 ± 0.4^{g}	296 ± 0.4^{c}	1323 ± 0.4^{f}	1892 ± 0.4^{h}	215 ± 0.4^{b}	1134 ± 0.4^{e}	2007 ± 0.4^{i}	1.8–2.3 g d^{-1**}
	K	2383 ± 0.5^{g}	2875 ± 0.4^{h}	3049 ± 0.4^{i}	1000 ± 0.5^{c}	1370 ± 0.4^{e}	1776 ± 0.4^{f}	383 ± 0.4^{a}	875 ± 0.4^{b}	1049 ± 0.4^{d}	3.75 g d^{-1**}
	Fe	3.9 ± 0.04^{a}	4.8 ± 0.04^{a}	17.3 ± 0.4^{b}	4.4 ± 0.05^{a}	6.3 ± 0.04^{a}	19.7 ± 0.4^{c}	5.4 ± 0.04^{a}	7.7 ± 0.05^{a}	15.7 ± 0.4^{b}	20 mg d^{-1**}
	Cu	0.44 ± 0.04^{ab}	0.88 ± 0.05^{bc}	1.23 ± 0.4^{cd}	0.04 ± 0.004^{a}	0.45 ± 0.045^{ab}	0.51 ± 0.04^{ab}	1.49 ± 0.5^{de}	1.79 ± 0.4^{ef}	2.02 ± 0.4^{f}	1700 µg d^{-1**}
	Zn	5.32 ± 0.4^{d}	6.16 ± 0.4^{d}	10.61 ± 0.5^{f}	0.99 ± 0.05^{a}	1.32 ± 0.4^{a}	5.44 ± 0.4^{d}	2.32 ± 0.4^{b}	3.16 ± 0.4^{c}	8.61 ± 0.5^{e}	12 mg d^{-1**}
	Mn	1.31 ± 0.4^{a}	2.17 ± 0.5^{b}	23.05 ± 0.5^{e}	2.45 ± 0.4^{b}	3.19 ± 0.4^{bc}	4.37 ± 0.5^{d}	2.82 ± 0.4^{bc}	2.99 ± 0.4^{bc}	3.31 ± 0.4^{c}	2 mg d^{-1**}
	P	2.81 ± 0.4^{a}	12.93 ± 0.4^{b}	23.68 ± 0.5^{d}	112.28 ± 0.4^{e}	122.34 ± 0.4^{f}	148 ± 0.4^{g}	18.75 ± 0.4^{c}	19.02 ± 0.4^{c}	19.04 ± 0.4^{c}	800 mg d^{-1*}
	Cr	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	960 µg d^{-1**}
Heavy metals (mg kg^{-1})	Hg	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	1.0 mg d^{-1***}
	As	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	1.1 mg d^{-1***}
	Cd	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	1.5 mg d^{-1***}
	Pb	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	< MRL	2.5 mg d^{-1***}
	Ni	0.88 ± 0.04^{g}	0.65 ± 0.05^{e}	0.56 ± 0.04^{d}	0.72 ± 0.04^{f}	0.75 ± 0.04^{f}	0.27 ± 0.04^{a}	0.62 ± 0.04^{de}	0.46 ± 0.04^{c}	0.39 ± 0.04^{b}	1.5 mg d^{-1***}

Values are expressed as mean ± SD (standard deviation) of triplet experiment on the same samples

$^{a-k}$Means with different superscript letters in each row are significantly different according to Duncan's multiple-range test ($p < 0.05$)

FSSAI: The Food Safety and Standard Authority of India; MRL: Minimum Reporting Limit

Source: *ICMR (2010); **https://www.enomark.com/page.php?name=FSSAI+Guidelines&pid=NzJSemk5QUVzOUJGOU9ObXVJWTZIQT09; ***https://www.indiaretailing.com/2016/08/11/food/food-grocery/the-importance-of-detecting-metals-in-food-beverages/

and presented in a panel room that was furnished with separate well lit and odour free booths. After each taste, the palate was washed with water to differentiate the individual samples taste. Then, the panelists were requested to mark their responses on the sensory questionnaire sheet [Bakery product attributes, such as appearance, color, aroma, taste, softness, crispiness, and overall acceptability, were surveyed using a five-point hedonic scale (1-disliked very much, 2-disliked moderately, 3-neither liked nor disliked, 4-liked moderately, and 5-liked very much)].

Statistical analysis

All samples were examined in triplicate using one-way analysis of variance (ANOVA). Duncan's multiple-range test ($p < 0.05$) was used to analyze the significant differences in the nutritional (biochemical components, minerals) and anti-nutritional (heavy metals) properties of seaweed bakery products. This was done using IBM SPSS statistics 21.0.

Results

Nutraceutical properties of seaweed bakery products

The proximate composition [protein (%), carbohydrate (%), lipid (%)], energy (kcal (100 g)$^{-1}$), and minerals (mg kg^{-1}) is represented in Fig. 1. All the selected nutraceutical properties exhibited specific differences ($p < 0.05$) than the conventional ones between seaweed products, which are a clear indication of the range of use of the two seaweeds (*U. lactuca* and *G. corticata*) with their different biochemical constituents (Table 2). The protein content was comparatively higher in the case of bread, cake, and cookies prepared with seaweeds than in the conventional ones [Protein (%): CBr: 12.23 ± 0.4 to GcBr: 16.85 ± 0.4; CCa: 9.38 ± 0.4 to GcCa: 14.53 ± 0.4; CCo: 14.16 ± 0.4 to GcCo: 20.16 ± 0.5]. Similar trends were also observed for carbohydrates, lipids, and energy (Fig. 1).

The mineral content was evaluated for all seaweed products (Figs. 1, 2). Duncan's post hoc analysis of seaweed bakery products showed comparatively higher mineral concentrations than the conventional products with significant difference ($p < 0.05$) excepting Cu in CBr, UlBr, GcBr, UlCa, GcCa, CCo, UlCo and GcCo and Mn in UlCa, CCo, and UlCo (Table 2). Moreover, in most cases, *G. corticata*-incorporated products showed comparatively higher values than those for *U. lactuca*. Cr was absent in both the seaweeds and their products.

Heavy metal analysis was performed for Hg, As, Cd, Pb, and Ni in seaweed-based products (bread, cake, and cookies). For the first four metals, the values were below the Minimum Reporting Limit (MRL). However, in the case of Ni the values ranged from 0.27 ± 0.04 mg kg^{-1} in GcCa to 0.88 ± 0.03 mg kg^{-1}in CBr. It was observed that the Ni concentration was comparatively lower in the seaweed-added products than in the conventional products for both bread and cookies. An exception to this was UlCa, where the Ni was slightly higher than that of the conventional product (Table 2). The analyzed heavy metal values of seaweed-added bread, cake, and cookies were significantly different ($p < 0.05$) from conventional goods excepting Ni in CCo (Table 2).

Microbial load

The TPC (cfu g^{-1}) ranged from 1296 ± 0.4 in GcCo to 16,165 ± 0.04 in CBr, while the TC (cfu g^{-1}) ranged from 431 ± 0.4 in UlCo to 4318 ± 0.4 in UlBr. In the case of

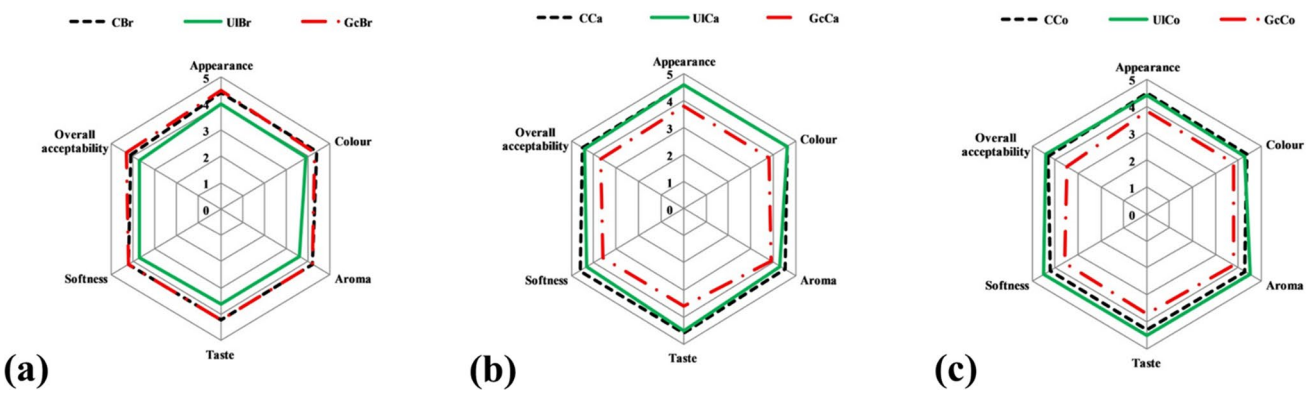

Fig. 2 Sensory evaluation of baked goods (**a**) seaweed bread and conventional bread, (**b**) seaweed cake and conventional cake and (**c**) seaweed cookies and conventional cookies. 1-disliked very much = 1.00–1.80, 2-disliked moderately = 1.90–2.60, 3-neither liked nor disliked = 2.70–3.40, 4-liked moderately = 3.50–4.20 and 5-liked very much = 4.30–5.00

Table 3 Microbial load in seaweed bakery products

Microbial load (cfu g^{-1})	CBr	UlBr	GcBr	CCa	UlCa	GcCa	CCo	UlCo	GcCo	FSSAI*	ELID**	IMS***
TPC	16,165 ± 0.4	12,801 ± 0.3	8222 ± 0.4	3685 ± 0.4	7900 ± 0.5	8535 ± 0.4	3484 ± 0.3	1530 ± 0.4	1296 ± 0.4	$< 10^5$ g^{-1}	10^5	10^5
Total Coliform	1533 ± 0.4	4318 ± 0.4	3392 ± 0.4	1137 ± 0.4	519 ± 0.5	2248 ± 0.5	1302 ± 0.4	431 ± 0.4	469 ± 0.4	Absent in 25 g	10^5–10	10^5–10^2
E. coli	nd	nd	2 ± 0.4	5 ± 0.4	7 ± 0.46	nd	3 ± 0.4	6 ± 0.4	3 ± 0.3	Absent in 25 g	10^6—> 10^7	$< 10^3$
V. cholera	nd	nd	nd	nd	nd	nd	nd	nd	nd	Absent in 25 g	1000	$< 10^3$
V. parahaemolyticus	nd	nd	nd	nd	nd	nd	nd	nd	nd	Absent in 25 g	10^6—10^9	$< 10^3$
S. typhi	nd	nd	nd	nd	74 ± 0.4	nd	nd	nd	nd	Absent in 25 g	10^4—10^{10}	$< 10^3$
S. dysenteriae	nd	nd	nd	nd	48 ± 0.4	nd	nd	nd	nd	Absent in 25 g	10—10^4	$< 10^3$
S. aureus	nd	nd	nd	nd	nd	nd	nd	nd	nd	Absent in 25 g	10^5—> 10^6	$< 10^3$

Values are expressed as mean ± SD (standard deviation) of triplet experiment on the same samples.

[a–g]Means with different superscript letters in each row are significantly different according to Duncan's multiple-range test ($p < 0.05$).

FSSAI: The Food Safety and Standard Authority of India; ELID: Expected Least Infectious Dose; IMS: International Microbiological Standard; MRL: Minimum Reporting Limit; nd: not detected

Source: *https://www.fssai.gov.in/upload/uploadfiles/files/Compendium_Food_Additives_Regulations_08_09_2020-compressed.pdf **Rao et al. (2018); ***Daniyan and Nwokwu (2011)

bread and cookies, the TPC of the seaweed products decreased, but the opposite was true in the case of the cake. The trend in TC was the reverse of that for TPC in the case of bread only, but it followed the same trend in the case of cookies. Interestingly, in the case of cakes the TC values decreased for *U. lactuca* and increased for *G. corticata* compared to the conventional one. Selected pathogens were present within the permissible level according to as the Expected Least Infectious Dose (ELID), International Microbiological Standard (IMS) and the FSSAI (Table 3). However, as per FSSAI the total coliform load was higher which may be probably due to the mixing of the coastal water with the anthropogenic outfalls (a normal phenomenon caused by the wave and tide of the sea). The seaweeds were not autoclaved to remove bacteria so that the biochemical constituents are not changed.

Physical, textural, and color characteristics of seaweed bakery products

The formulation for the bread, cake, and cookies and, their proportion of seaweeds (*U. lactuca* and *G. corticata*) are summarized in Table 1, along with the fermentation, proofing, bakery temperature, and duration details. The addition of 2 g seaweed powder to the dough and batter increased the physical, textural, and color characteristics of bread, cake, and cookies (Plate 1) when compared with those of the conventional products (bread, cake, and cookies).

Regarding physical properties, the weight (g) of dough and batter showed 2–4 points more than that of the conventional products, which decreased considerably compared to that of the conventional products after fermentation and baking. The amount of weight loss in the case of bread after fermentation ranged from 1.13 ± 0.4 to 2.8 ± 0.4%, whereas that after baking ranged from 8.11 ± 0.3 to 10.5 ± 0.5%. In the case of cake, the weight loss percentage was comparatively lower (24.29 ± 0.4 to 97 ± 0.5%), but it was inflated in the case of cookies (10.42 ± 0.4 to 13.0 ± 0.4%). The specific gravity for the batter was between 0.7 ± 0.04 and 0.75 ± 0.04. Moreover, the volume (cm^3) of the bread and cake was almost uniform for the conventional and experimental groups, whereas the volume increased to almost double in the case of cookies. The specific volume also followed a similar trend to that ofthe specific gravity. The density (g cm^{-3}) increased in the case of experimental bread, remained unchanged for cakes, and was reduced in the case of raw cookies. However, after baking, the density of the cookies was reduced by almost half of the original value. Regarding the diameter (cm), there was no change with the cake and a slight increase with the cookies in comparison to the conventional. However, after baking,

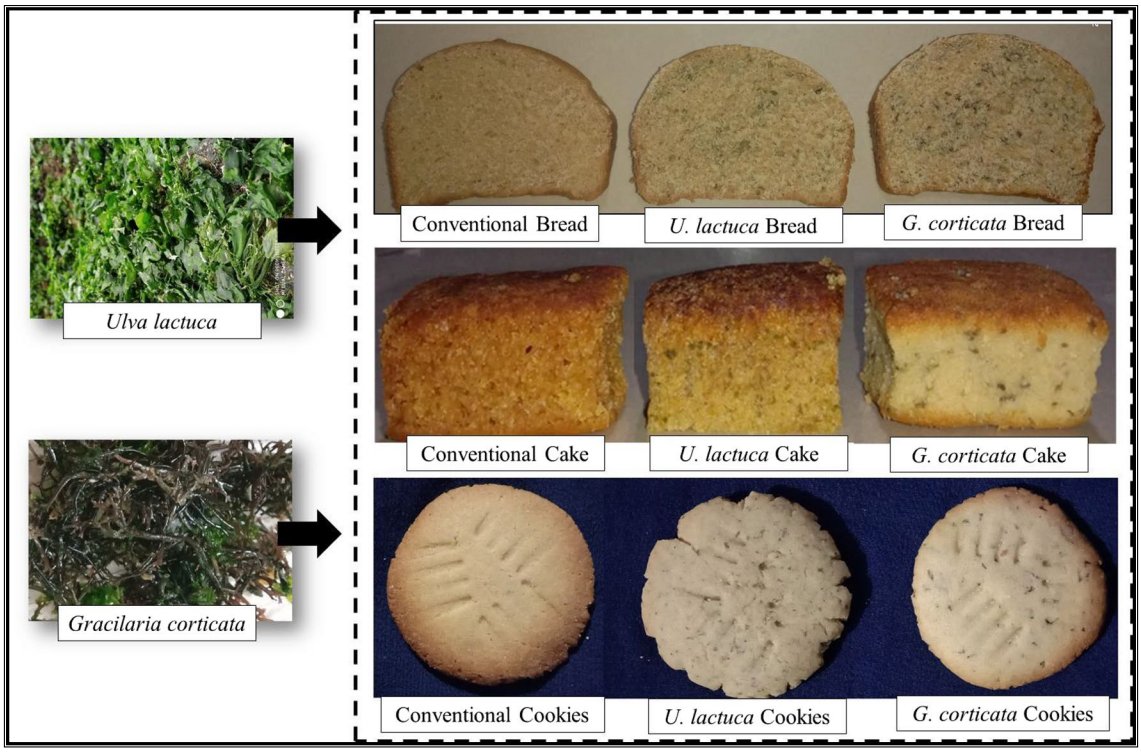

Plate 1 Pictorial representation of the seaweeds and its prepared bakery products

these values increased by 0.4–0.5 units. The height (cm) and thickness (cm) of the bread slices were more or less uniform for bread, while a very slight increase was observed in the case of cakes and cookies. The spread ratio decreased by 0.1–0.2 units in the case of cake, but decreased by 0.2–0.8 units in the case of raw and baked cookies (Table 4).

Concerning textural properties, the hardness (N) values were more or less similar between the experimental bread and the conventional bread. However, it was greater in the case of cakes and cookies than in the conventional products. Adhesiveness (Ns) was generally uniform for the conventional and experimental bread and cakes. Springiness decreased (mm) for all the experimental products compared to the conventional products, which is similar to what was seen for the cohesiveness and gumminess (N). Chewiness (mg) followed the same trend for bread and cake, but slightly increased in the case of cookies (Table 4).

Color analysis showed that the lightness (L^*) value of the crust and crumb of the bread, cake, and cookies followed the same trend, which is a decreased value with *U. lactuca* addition and an increased value with the addition of *G. corticata*. The redness (a^*) value in the case of bread followed a similar trend to the lightness (L^*) value, whereas in the case of cake, it increased, and in the case of cookies it decreased compared to the conventional products. The yellowness (b^*) values decreased in the crust of bread, cakes, and cookies. However, in the case of the crumb, the yellowness (b^*) values decreased with the addition of *U. lactuca*, but increased on the addition of *G. corticata*. The color differences in GcBr and GcCo can be classified as very distinct [total colour difference (ΔE^*) > 3.0)], whereas those in UlBr, UlCa, UlCo, and GcCa can be classified as small differences [total colour difference (ΔE^*) > 1.5)] (Table 4).

The sensory evaluation was performed by 57.7% of male and 42.3% of female eavuators where the maximum members were within the 20–29 age groups (71.2%) and were mostly qualified with post-graduate degrees (55.8%). The mean scores of the hedonic sensory attributes of bakery products (bread, cake, and cookies), such as appearance (A), color (C), aroma (Ar), taste (T), softness (S), crispiness (Cr), and overall acceptability (OA), are shown in Fig. 2. From the radar chart report, the conventional products (Bread: A-48.1%, C-46.2%, Ar-36.5%, T-46.5%, S-40.4%, OA-36%; cake: A-65.4%, C-63.5%, Ar-60%, T-58.8%, S-62.7%, OA-60.8% and cookies: A-62.7%, C-54.9%, Ar-45.1%, T-51%, Cr-37.3% OA-47.1%) have scored the highest point in comparison to seaweed products. However, in case of appearance (GcBr-60.8%), aroma (GcBr-38.5%, UlCo-62.7%), taste (UlCa-64.7%, UlCo-58.8%), crispiness (UlCo-58.8%) and overall acceptability (GcBr-46.2%, UlCo-47.1%),

Table 4 Physical, texture and colour characteristics of bread, cake and cookies

		CBr (100 g WWF)	UlBr (100 g WWF)	GcBr (100 g WWF)	CCa (100 g WF)	UlCa (100 g WF)	GcCa (100 g WF)	CCo (100 g WWF)	UlCo (100 g WWF)	GcCo (100 g WWF)
Physical	Weight of dough; Batter (g)	177 ± 0.4	181 ± 0.5	180 ± 0.4	242.9 ± 0.4	244.9 ± 0.4	245.9 ± 0.5	240.5 ± 0.5	244 0 ± 0.5	242.5 ± 0.5
	Weight of dough AF; AB weight (g)	175 ± 0.4 (AF): 156.6 ± 0.5 (AB)	177 ± 0.4 (AF): 162.6 ± 0.4 (AB)	175 ± 0.4 (AF): 160.8 ± 0.4 (AB)	183.9 ± 0.4(B)	184.3 ± 0.4 (B)	184.5 ± 0.4(B)	23 ± 0.45 (R): 20 ± 0.4(B)	24 ± 0.5 (R): 21.5 ± 0.4 (B)	23.5 ± 0.4 (R): 21 ± 0.4 (B)
	Specific gravity of batter	-	-	-	0.7 ± 0.04	0.72 ± 0.04	0.75 ± 0.04	-	-	-
	Volume (cm^3)	917 ± 0.4	916.5 ± 0.4	916.2 ± 0.4	397.2 ± 0.4	397.5 ± 0.41	397.7 ± 0.4	19.63 ± 0.4 (R): 35.62 ± 0.4 (B)	29.76 ± 0.4 (R): 47.5 ± 0.5 (B)	26.46 ± 0.4 (R): 43.36 ± 0.4 (B)
	Specific volume (cm^3g^{-1})	5.85 ± 0.4	5.64 ± 0.4	5.70 ± 0.5	2.16 ± 0.4	2.16 ± 0.5	2.16 ± 0.5	0.85 ± 0.04 (R): 1.78 ± 0.5 (B)	1.24 ± 0.5 (R): 2.21 ± 0.4 (B)	1.13 ± 0.4 (R): 2.07 ± 0.4 (B)
	Density (gcm^{-3})	0.171 ± 0.04	0.177 ± 0.04	0.176 ± 0.04	0.46 ± 0.05	0.46 ± 0.04	0.46 ± 0.04	1.17 ± 0.4 (R): 0.56 ± 0.04 (B)	0.81 ± 0.05 (R): 0.45 ± 0.04 (B)	0.89 ± 0.04 (R): 0.48 ± 0.05 (B)
	Diameter (D) (cm)	-	-	-	10.0 ± 0.4285	10.0 ± 0.4115	10.0 ± 0.4438	5.0 ± 0.4 (R): 5.5 ± 0.4 (B)	5.4 ± 0.4 (R): 5.8 ± 0.4 (B)	5.3 ± 0.4 (R): 5.7 ± 0.5 (B)
	Height (H); Thickness (T) (cm)	7.1 ± 0.4 (H); 1.25 ± 0.4 (T) (slice)	6.8 ± 0.4 (H); 1.25 ± 0.4 (T) (slice)	7.0 ± 0.4 (H); 1.25 ± 0.4 (T) (slice)	4.0 ± 0.4 (H)	4.2 ± 0.4 (H)	4.5 ± 0.4 (H)	1.0 ± 0.5 (RT): 1.5 ± 0.4 (BT)	1.3 ± 0.4 (RT): 1.8 ± 0.5 (BT)	1.2 ± 0.4 (RT): 1.7 ± 0.5 (BT)
	Spread ratio (D/T) OR (D/H)	-	-	-	2.5 ± 0.4	2.4 ± 0.4	2.2 ± 0.5	5.0 ± 0.4 (R): 3.66 ± 0.5 (B)	4.15 ± 0.4 (R): 3.2 ± 0.4 (B)	4.42 ± 0.4 (R): 3.35 ± 0.4 (B)
	Weight loss (%)	1.13 ± 0.4 (AF): 10.5 ± 0.5 (AB)	2.21 ± 0.4 (AF): 8.14 ± 0.4 (AB)	2.8 ± 0.4 (AF): 8.11 ± 0.4 (AB)	24.29 ± 0.4	24.75 ± 0.4	24.97 ± 0.5	13.0 ± 0.4	10.42 ± 0.4	10.64 ± 0.4
Texture	Hardness (N)	2.6 ± 0.5	2.8 ± 0.4	2.65 ± 0.4	1.58 ± 0.4	1.65 ± 0.4	1.77 ± 0.4	145.66 ± 0.5	158.8 ± 0.4	150.5 ± 0.4
	Adhesiveness (N s)	0.22 ± 0.05	0.19 ± 0.05	0.21 ± 0.04	0.04 ± 0.004	0.03 ± 0.004	0.01 ± 0.004	-	-	-
	Springiness (mm)	0.85 ± 0.05	0.78 ± 0.04	0.81 ± 0.04	0.80 ± 0.5	0.78 ± 0.04	0.76 ± 0.04	1.3 ± 0.4	0.90 ± 0.04	0.95 ± 0.04
	Cohesiveness	0.66 ± 0.04	0.60 ± 0.04	0.62 ± 0.04	0.65 ± 0.05	0.61 ± 0.04	0.60 ± 0.04	0.70 ± 0.04	0.65 ± 0.05	0.67 ± 0.05
	Gumminess (N)	0.88 ± 0.04	0.75 ± 0.04	0.80 ± 0.04	2.76 ± 0.4	2.65 ± 0.4	2.60 ± 0.40	0.23 ± 0.04	0.08 ± 0.004	0.13 ± 0.05
	Chewiness (mg)	5.22 ± 0.4	4.96 ± 0.4	5.10 ± 0.4	2.30 ± 0.5	2.28 ± 0.5	2.26 ± 0.4	5.0 ± 0.4	5.3 ± 0.5	5.1 ± 0.4

Table 4 (continued)

		CBr (100 g WWF)	UlBr (100 g WWF)	GcBr (100 g WWF)	CCa (100 g WF)	UlCa (100 g WF)	GcCa (100 g WF)	CCo (100 g WWF)	UlCo (100 g WWF)	GcCo (100 g WWF)
Colour	L^*	45.23 ± 0.4 (C1): 63.33 ± 0.4 (C2)	44.83 ± 0.5 (C1): 62.95 ± 0.5 (C2)	46.09 ± 0.4 (C1): 64.12 ± 0.4 (C2)	66.44 ± 0.4	65.30 ± 0.4	67.82 ± 0.4	64.22 ± 0.4	63.60 ± 0.4	70.22 ± 0.4
	a^*	13.65 ± 0.4 (C1): -0.38 ± 0.04 (C2)	13.32 ± 0.4 (C1): -0.15 ± 0.05 (C2)	14.02 ± 0.4 (C1): 0.68 ± 0.04 (C2)	-0.88 ± 0.05	-1.77 ± 0.4	-1.86 ± 0.5	6.33 ± 0.4	5.02 ± 0.4	5.44 ± 0.4
	b^*	35.08 ± 0.5 (C1): 11.26 ± 0.4 (C2)	32.16 ± 0.4 (C1): 10.98 ± 0.5 (C2)	32.52 ± 0.5 (C1): 14.56 ± 0.4 (C2)	25.65 ± 0.4	24.34 ± 0.4	25.60 ± 0.5	25.87 ± 0.4	24.22 ± 0.4	24.52 ± 0.4
	ΔE^*	-	2.97 ± 0.4 (C1) 0.53 ± 0.04 (C2)	2.73 ± 0.4 (C1) 3.6 ± 0.4 (C2)	-	1.95 ± 0.4	1.69 ± 0.4	-	2.20 ± 0.4	6.21 ± 0.5

WWF Whole wheat flour, *WF* White flour, *AF* After fermentation, *AB* After baking, *C1* Crust, *C2* Crumb, *R* Raw, *B* Baked, *RT* Raw thickness, *BT* Baked thickness, L^* lightness, a^* redness, b^* yellowness, ΔE^* Total colour difference

the seaweed products have recorded the maximum score. Therefore, among all seaweed bakery products, UlCa recorded the maximum acceptability of 5 point rating scale (liked very much with 64.7%) whereas; UlBr has scored the minimum acceptability of 1 point rating scale (disliked very much with 7.8%)(Fig. 2).

Discussion

Having a nutrient-deficient diet leads to major diseases, such as cancer, heart disease, and osteoporosis (Bhan et al. 2003). Therefore, nutrition-enriched functional foods should be consumed to activate the immune system (Alexander et al. 1998). While minerals constitute a micronutrient group, according to the WHO, they are essential for the production of enzymes, hormones, and other substances crucial for growth and development in humans. Apart from neuromuscular transmission, minerals also help with blood clot formation and oxygen transport (NRC 1989). Although minerals and trace elements (Hg, As, Cd, Pd, and Ni) are required in very small amounts, their deficiency in the body causes serious consequences. The addition of seaweeds in the formulation of bakery products has improved its biochemical components due to the increase in the content of protein, carbohydrate, and lipid. Other researchers with different seaweed have also reported the similar results [Protein (P):Mamatha et al. (2007)—Pakoda-*Enteromorpha*-↑(P); Prabhasankar et al. (2009)—Noodles-*U.pinnatifida*-18.7 to 21.7% (P); Senthil et al. (2011)—Instant spices- *K. alvarezii*- ↑(P); Cian et al. (2014)—Extruded maize-*P. columbina*-↑(P)-$p < 0.05$; Kumoro et al. (2016)—Instant fried noodles-*Eucheuma cottonii*-9.34 to 16.92 g $(100\ g)^{-1}$(P); Pérez-Alva et al. (2022)—Tortillas-*Macrocystis pyrifera*-↑(P); carbohydrate in form of dietary fibre (DF): Prabhasankar et al. (2009)—Noodles-*U. pinnatifida*-↑-$p < 0.05$ (DF); Hall et al. (2012)—Bread: *A. nodosum*-↑34%(DF); Cox and Abu-Ghannam (2013a, b)—Breadsticks- *H. elongata*-4.65 to 7.95% (DF); Kumoro et al. (2016)—Instant fried noodles-*E. cottonii*-(DF)↑; Huang and Yang (2019)—Cake-*E. cottonii*- 1.5 to 8.1%(DF) and lipid in form of fat (F): Prabhasankar et al. (2009) – Noodles-*U. pinnatifida*- ↑- $p < 0.05$(F); López-López et al. (2009a, b)—Beef patty—*U. pinnatifida*-↑(F); Kumoro et al. (2016)—Instant fried noodles—*E. cottonii*-↑(F)]. The data obtained for proximate composition in the prepared products were well within the acceptance ranges of the FSSAI (Table 2; Fig. 1).

The data on minerals in the present study are in agreement with Cian et al. (2014). The mineral content showed a significant loss in the conventional baked products in comparison to the mineral concentration present in seaweed. This was different for the contents of K (in bread) and

P (in UlBr, UlCa, GcCa, and UlCo), where the mineral content increased. Apart from the ingredients added to the conventional products, the addition of seaweed led to an increase in the value of K and P in the experimental products, similar Ni. similar results were recorded by Mamatha et al. (2007)—Pakoda -*Ulva*-↑Ca, Fe, López-López et al. (2009a)—Pork products –*U.pinnatifida* and *P. umbilicalis*-↑K, Ca, Mg, Mn, López-López et al. (2009b)-Frankfurters -*H. elongata*-↑Na, K, Ca and Pérez-Alva et al. (2022) -Tortillas -*M.pyrifera*-↑Ca, Na, P, K, Mg respectively. However, all the values for minerals and heavy metals are within the FSSAI limits of the Government of India. K is necessary for the neurological functioning within the human body, whereas P is an important ingredient for building bone and teeth strength. Ni is required by human body in small proportion for maintaining normal activities and lipid metabolism. Therefore, increased levels of these three minerals are not expected to negatively affect human health.

Seaweed products have already been used as various food ingredients by various food industries (Kılınç et al. 2013; Onyango et al. 2021). Furthermore, seaweed added bread, cakes, and cookies have been reported to provide protein, energy, and minerals to human beings (Quitral et al. 2021).

In 2007, the Food Agriculture and Organization (FAO) reported that approximately 2.5 billion people worldwide consume street food each day. In bakery products, microorganisms play an important role in maintaining the formation and consistency of flavor, which often becomes impaired or spoiled (Frazier and Westhoff 1978). Although spoilage and deterioration cannot be completely avoided, the rate of deterioration can be decreased through formulation, processing, packaging, storage, and handling (Bailey and Holy 1993). In developed countries, the quality of bakery products is strictly maintained under several laws and regulations, whereas appropriate microbiological safety and hygiene are often overlooked to a greater extent in developed and underdeveloped countries. Unhygienic surroundings often cause bacterial contamination of bakery products, the most common being pathogenic bacteria such as *E. coli*, *Vibrio* sp., *Salmonella* sp., *Shigella* sp., and *Staphylococcus* sp. Notably, various studies have reported that *E. coli* and *Salmonella* spp. can cause numerous illnesses and fatalities after food poisoning outbreaks. Our data on microbial load are well within the standards of the ELID and IMS. Moreover, the microbial load recorded for the preparation of bakery products matches the data of Abirami and Kowsalya (2012). Hence, the products prepared in this study can be recommended for public health use.

High-quality bakery products have several attributes such as high volume, softness, long shelf life, tolerance to tailing, and uniform crumb structure. Hence, seaweed bakery products are greatly influenced by the addition of hydrocolloids. Seaweeds absorb moisture and are rich in hydrocolloids, which influence the color, flavor, and nutrients of food. Therefore, the addition of seaweed powder to bakery products helps to increase the development and stability of the dough. Notably, bread formation is a result of crumb formation, which increases with the addition of seaweed powder.

Sensory analysis correlated well with the textural profile of the bakery products (Fitzgerald et al. 2014). In our study, adding seaweed powder (2 g) caused a reduction in bread volume, unlike what was seen with the cakes and cookies. This has also been reported by Różyło et al. (2017).Mouth feel analysis of the cookies has revealed crunchy, granular, and flaky characteristics, as observed by Jemziya and Mahendran (2017). The change in the diameter and thickness of the cookies reflects the spread ratio, which is considered the most important quality parameter for biscuits/cookies. Generally, the spread ratio is affected by dough expansion by leavening and gravitational flow. As the thicknesses of our cookies were greater than those of the conventional cookies, the spread ratio was adequate (Agrahar-Murugkar et al. 2015). In cakes, high oil retention capacity improved their mouth feel and flavor, as observed by Kinsella (1976). The incorporation of seaweed into cake increased the nutritional quality of the product with acceptable sensory attributes. The organoleptic acceptability of bread, cake, and cookies for *U. lactuca* and *G. corticata* is 1–5 on the hedonic scale (Vijay 2017), which proves that UlCa and UlCo are better than *G. corticata*, whereas GcBr is better than the others.

Incorporation of 2 g of seaweed powder enhanced the scores of GcBr, UlCa, and UlCo with regard to aspects such as appearance, aroma, taste, and crispiness, whereas UlBr, GcCa, and GcCo showed the lowest scores in overall acceptability. This is probably due to the higher water absorption capacity of *U. lactuca*, which in turn might be due to the enhanced solubility of proteins and fibers (Fleury and Lahaye 1991). However, the higher oil absorption capacity of *G. corticata* facilitates the compatibility of food blends and creates high-fat bakery products (Benjama and Masniyom 2012).

This contrasting feature of the two seaweeds has led to the sustained softness of bread and cake, and the development of crispiness in cookies. Somehow, conventional bakery products attained the maximum acceptability score for overall attributes. However, the appearance, aroma, taste, and crispiness of the seaweed-added bakery products were the major attributes according to panelist acceptance, which should be considered when comparing the conventional products, because of the nutritional benefits of the seaweed-added goods.

Conclusion

Seaweeds have great potential as functional foods. The present study revealed that the addition of 2 g of seaweed powder (*U. lactuca* and *G. corticata*) to baked goods can be used to enhance their quality. In addition, surveys on their physical and palatability properties have supplemented what already exists in present research. Nevertheless, further research on itspackaging and marketing can lead to improved marketability. Hence, the study recommends for using cultured seaweed for making bakery products rather than open water. Moreover, an awareness program is required to establish seaweed-based products for the consumption of the general population, which can improve the nutrient intake and immune system function.

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Data availability The datasets used and/or analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval The tasting trial was done using 52 respondents with the approval of our Central University of Odisha Ethical Committee.

Conflict of interest The authors declare that there is no conflict of interest.

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