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EFFECT OF DIFFERENT ALGAL LEES ON PHYSICOCHEMICAL QUALITIES OF BAKED POTATO CHIPS

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Key words: potato chips, algal lees, antioxidant activity, sensory.

ABSTRACT

Lees of three different algae (a green alga *Ulva fasciata*, a brown alga *Sargassum cristaefolium* and a red alga *Kappaphycus contonii*), representing the leftovers from a seaweed polysaccharide extraction process using hot water and enzymes, were added separately to potato chip dough at a level of 2.5%. Antioxidant activity, water activity, color, firmness, overall acceptability and proximate composition of baked potato chips prepared from these dough and from dough without algal lees were evaluated. The rehydration capacity (49.87%) of red algal lees was significantly higher than that of the other lees. The firmness of baked potato chips with red algal lees added was also the highest. The water activity of chips with algal lees was significantly less than that of control chips without lees ($p < 0.05$). Adding red algal lees increased the ferrous ion chelating activity of the baked potato chips compared to the control ($p < 0.05$). The addition of algal lees increased the protein, ash and dietary fiber contents of baked potato chips. Sensory scores showed that red algal lees could be added to baked potato chips at a 2.5% level without affecting acceptability, but at that level green and brown algal lees produced an unacceptable dark color and strong seaweed flavor. Overall, red algal lees seem the best candidate as an algal supplement in baked potato chips.

I. INTRODUCTION

The leading causes of death in most of the developed world are chronic diseases. Factors increasing the risk of developing chronic disease include smoking, dietary habits, physical inactivity and alcohol use. Therefore, finding inexpensive and healthful ingredients to improve people's diets is an important task for the food industry. There has been increasing interest in recent years in the potential health benefits of bioactive compounds derived from seaweeds (Ibanez et al., 2012). Algae also exhibit antioxidant, antiviral and antifungal properties (Marinho-Soriano et al., 2006). Several methods have been used in the literature to test the efficiency of antioxidants in food extracts as an index of antioxidant status *in vivo* (Jan et al., 2015; Morales et al., 2009). These tests are based on different mechanisms of the antioxidant defense system, such as the scavenging of hydroxyl radicals and oxygen ions, chelation of metal ions, inhibition of lipid peroxidation or reduction of lipid peroxyl radicals (Morales et al., 2009).

Seaweeds are rich in diverse functional polysaccharides (Costa et al., 2010). These functional ingredients are usually extracted by the use of high volume food-grade solvents and long extraction processes. However, traditional extraction techniques often result in low extraction yields of bioactive compounds. Seaweed lees are the remnants of the edible parts of algae and their carbohydrates that are resistant to digestion and absorption in the human small intestine, as well as by-products of industrial algal extraction process. They are rich in dietary fiber and mineral content, as well as bioactive residues.

Food with functional dietary fiber has drawn ever more attention due to its good performance in regard to its physiological function as well as its acceptable taste (Morales et al., 2009). Dietary fiber is an inexpensive and healthful ingredient which may prevent some chronic diseases (Hong et al., 2012). Algal lees can be dried and ground to powder that can be incorporated easily into various liquid and solid foods. However, the use of algal lees as a source of fiber may influence the aroma and textural properties of processed food. Lees also need to be assessed in terms of consumer acceptability and baking performance, which are considered to be the key factors limiting or facilitating their successful use. Until now, there has been little work evaluating the acceptability of baked products with added algal lees, or the functional properties of such baked products.

In this study, lees of three species of green, brown and red alga, the residue from a seaweed polysaccharide extraction process using boiling water, cellulase and proteinase, were added to potato chip dough prior to baking. The effects of adding algal lees on various qualities of the potato chips, and their antioxidant activities after baking, were investigated. The results of the present study will be beneficial to the baking industry and also help to

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deal with the problems of algal extraction residue.

II. MATERIALS AND METHODS

1. Raw Materials and Chemicals

Quantities of the intertidal green alga *Ulva fasciata*, brown alga *Sargassum cristaefolium* and red alga *Koppaphycus contonii* were collected from the Badouzi Coastal Park (Keelung, Taiwan) at low tide and transported immediately in seawater to the Taiwan Algal Research Center, where they were identified and sorted. The algae samples were washed thoroughly with fresh water to remove salt and then oven-dried at 60°C for 48 h. After grinding, dried seaweed powder (1,000 g) was suspended in 10 l of water and boiled for 1 h. The suspension solution was cooled and cellulase and proteinase were added (details withheld due to patent application); the solution was boiled again to stop the enzyme activity. The functional polysaccharides were filtered by vacuum suction using a Buchner funnel and analytical-grade filter paper, and the residue of the seaweed extracts, designated as seaweed lees, were freeze-dried in a bulk tray dryer (Labconco Co., Kansas City, USA). The dry matter from the freeze-drying process was ground and stored in desiccators.

Potato mash premix, tapioca starch, shortening, black pepper powder and salt (NaCl) were purchased from a baking products retail shop (Ai Ga, New Taipei City, Taiwan). Sodium hydroxide, boric acid, sulfuric acid, methyl red, 1, 1-diphenyl-2-picrylhydrazyl, ferrous chloride 4-hydrate and ferrozine (3-(2-pyridyl)-5, 6-bis (4-phenylfulfonic acid)-1, 2, 4-triazine were purchased from Panreac (Barcelona, Spain). All reagents used were of analytical grade.

2. Potato Chip Preparation and Proximate Composition of Baked Potato Chips

The ingredients of the experimental potato chip dough included 100 g potato mash premix, 120 g tapioca starch, 60 g shortening, 3.2 g black pepper powder, 1.2 g salt and 24 ml water (H_2O) in addition to 8 g of one of the three kinds of freeze-dried algal lees. No algal lees were added to the control dough. The ingredients were mixed in a vertical mixer with a paddle attached. The dough was rolled out and cut into discs with a diameter of 6.0 cm and thickness of 3 mm and baked in an electric oven first at 170°C for 20 min and then at 150°C for an additional 10 min. The moisture, ash and protein content of the baked potato chips were measured according to AACC procedures 44-15A, 46-12 and 46-30, respectively (AACC, 2000). The water activity of the baked potato chips was determined using an RTD-33 TH-1-NOVASINA avumeter (Novasina Co. Ltd., Pfaffikon, Switzerland). Three grams of mashed baked potato chip sample were put in the sample compartment for each measurement.

Two g of freeze-dried algal lees of each of the three kinds of algae were placed separately in 100 ml distilled water and held at room temperature (rt) (25°C) for 1 h. The suspension was filtered by vacuum suction using a Buchner funnel and analytical-grade filter paper.

3. Rehydration Capacity

Rehydration capacity (%) = (weight of rehydrated algal lees after filtering – weight of powdered algal lees) / weight of powdered algal lees.

4. Textural Characteristics of Baked Potato Chips

Hardness of the baked potato chips was determined using a Brookfield CT3 Texture Analyzer (Brookfield, USA) coupled with CT V1.4 software according to the methods of Pineli et al. (2015) with a slight modification. Compression tests were conducted using a TA-39 probe and TA-DE base, a load of 10 g as trigger and a test speed 1.0 mm/s.

5. Sensory Evaluation of Baked Potato Chips

Baked potato chips were evaluated by 50 panelists based on the principles of sensory evaluation of food (Amerine et al., 1965). All panelists were faculty and students of the Department of Food Science, National Taiwan Ocean University. Most of them had experience with sensory evaluation techniques and were instructed to evaluate appearance, color, aroma, crispness, flavor, oily sensation and overall acceptability. Each attribute was scored on a seven-point hedonic scale ranging from “1 = dislike extremely” to “7 = like extremely”. Potato chip samples coded with three digits were supplied to the panelists, each of whom received three chips representing all three treatments and a control chip, presented in random order on a tray. All trials were conducted between 16:00 and 17:00 at 25°C with adequate lighting, continuous circulation of air and no disturbing noise.

6. Sample Extraction for Antioxidant Assays

Potato chip samples (4 g each of controls and chips with three kinds of algal lees) were blended and suspended in 28 ml of deionized water at 30-40°C in a centrifuge tube. The tube was shaken vigorously for 5 min and left to stand for 30 min at 4°C. The mixture was centrifuged at 10,000 *g* for 10 min (CR21G, HITACHI, Tokyo, Japan) at 4°C to remove undissolved centrifuge debris. The supernatant was collected and added to 8 ml of deionized water (30-40°C), mixed with a vortex mixer and centrifuged again as in the above procedure. After the second centrifugation, the solution was filtered with 0.45 μm PEFE and stored as potato chip extract at -50°C until use. Each test was conducted on three replicates.

7. DPPH Radical Acavenging Assay

The scavenging effects of potato chip extract for 1, 1-diphenyl-2-picrylhydrazyl hydrate (DPPH) were determined spectrophotometrically according to the method of Morales et al. (2009), with slight modification. A 100 μl of aliquot of baked potato chip extract was added to 100 μl of 0.1 mM DPPH methanolic solution. The mixture was left to stand at rt for 30 min in the dark. The absorbance was read at 517 nm, and the radical scavenging effect was calculated using the following equation:

$$\text{Scavenging effect (\%)} = (1 - (A_{\text{sample}}) / A_{\text{sample blank}}) \times 100\%$$

Table 1. Proximate composition of baked potato chips with different kinds of algal lees added.

	Control	Red alga (*Kappapahycus cotonii*)	Brown alga (*Sargassum cristaefolium*)	Green alga (*Ulva fasciata*)
Moisture (%)	1.98 ± 0.11^c	3.44 ± 0.03^a	1.89 ± 0.18^c	2.46 ± 0.05^b
Crude ash (%)	2.28 ± 0.55^c	4.72 ± 0.32^a	5.19 ± 0.19^a	3.74 ± 0.04^b
Crude protein (%)	2.64 ± 0.2^c	3.7 ± 0.22^b	3.99 ± 0.09^b	5.69 ± 0.06^a

Note: Data are shown as mean ± standard deviation. Data with different superscript letters within the same row are significantly different ($p < 0.05$; $n = 3$).

where A_{sample} is the absorbance of the test sample (DPPH plus test sample), and $A_{sample\ blank}$ is the absorbance of the sample only (sample without DPPH solution).

8. Ferrous Ion Chelating Activity

Assays of ferrous ion chelating activity were performed using the method of Jan et al. (2015), with slight modification. A mixture of 100 μl potato chip extract, 8 μl of 1% ferrozine and 4 μl of 0.1% $FeCl_2$ was prepared. The mixture was left to stand at rt for 10 min in the dark. The absorbance was read at 562 nm. The ferrous ion chelating activity was calculated using the following equation:

$$\text{Ferrous ion chelating activity (\%)}$$
$$= (1 - (A_{sample}) / A_{sample\,blank}) \times 100\%$$

where A_{sample} is the absorbance of the test sample with reagent, and $A_{sample\ blank}$ is the absorbance of the sample only.

9. Chromaticity Testing

Baked potato chip color was examined using a spectrocolorimeter (TC-1800 MK II, Tokyo, Japan) measuring the L (lightness), a (redness/greenness) and b (yellowness/blueness) color scales. A white tile and a black cup were used to standardize the spectrocolorimeter. The color of the baked chips was recorded with three measurements for each sample and three samples per treatment and control. White Index (*WI*) was calculated according to the following equation:

$$WI = 100 - \left[(100 - L)^2 + (a)^2 + (b)^2 \right]^{1/2}$$

10. Statistical Analysis

A completely randomized block design was used with three replications per treatment and control for all the above assays and tests. Data were analyzed by analysis of variance using the SPSS statistic program for Windows Version 12 (SPSS Inc., Chicago, IL, USA). Duncan's multiple range test was used to identify the difference between treatments at a 5% significance level ($p < 0.05$).

III. RESULTS AND DISCUSSION

1. Chemical Composition of Baked Potato Chips

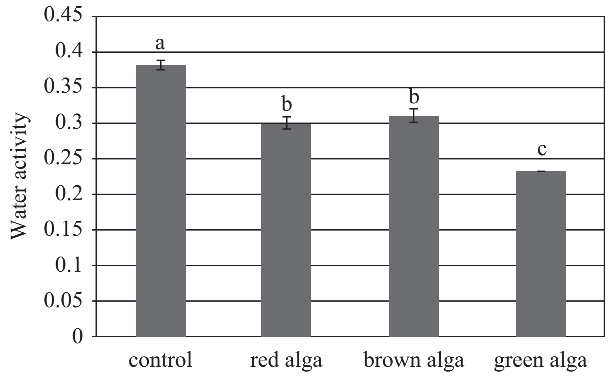


Fig. 1. Water activity of baked potato chips with different algal lees added. a-c indicate significant differences between different kinds of potato chips ($p < 0.05$).

Table 1 lists the proximate compositions of the baked potato chips with algal lees added. The addition of lees significantly increased the ash, protein and dietary fiber contents of the baked potato chips. Judging from these data, red and brown algal lees appeared to be potential sources of minerals, while green algal lees a potential source of protein, for humans. For red algae, protein content was found to range from 5.6% to 24% in *Gracilaria* and 2.7% to 24.5% in *Laurencia* species (Marrion et al., 2005; Renaud and Luong-Van, 2006; Wen et al., 2006; Marinho-Soriano et al., 2007), and four Brazilian red algal species contain large amounts (24.2%-28.4%) of aspartic and glutamic acids, which together constitute a large part of the amino acid fraction of most seaweeds (Gressler et al., 2010). Rohai-Ghadikolaei et al. (2012) demonstrated that the protein content of red (*Hypnea valentiae* and *Gracilaria corticata*) or green (*Ulva lactuca* and *Enteromorpha intestinalis*) seaweeds was significantly higher ($p < 0.05$) compared to brown seaweeds (*Sargassum iliciforlium* and *Colpomenia Sinuosa*). Seaweeds contained higher concentrations of the minerals (potassium, magnesium, iron, manganese, copper, zinc and cobalt) than the terrestrial vegetables in Persian Gulf. Higher potassium contents were reported in the brown and red Persian Gulf seaweeds as compared to the green seaweeds (Rohani-Ghadikolaei et al., 2012).

The water activity of baked potato chips with green algal lees added was significantly lower than in the other treatments and control (Fig. 1). Dietary fiber additions to dough generally yielded a higher absorption capacity, which in turn led to a longer shelf life (Hong et al., 2012). The moisture content of green, brown and red algal lees was 2.20 ± 0.39%, 1.75 ± 0.31%, and 0.47 ± 0.37%, respectively. The rehydration capacity (49.87%) of lees

Table 2. Sensory evaluation of baked potato chips with different algae lees added.

	Control	Red alga (*Kappapahycus cotonii*)	Brown alga (*Sargassum cristaefolium*)	Green alga (*Ulva fasciata*)
Appearance	6.9 ± 1.6^a	6.9 ± 1.5^a	4.2 ± 1.7^b	4.1 ± 2.1^b
Uniformity of color	7.0 ± 1.5^a	6.8 ± 1.4^a	4.9 ± 1.9^b	5.2 ± 2.0^b
Aroma	6.0 ± 1.8^a	5.6 ± 1.9^a	3.7 ± 1.2^b	3.4 ± 1.2^b
Crispness	6.2 ± 1.7^a	6.4 ± 1.8^a	5.2 ± 1.9^b	4.8 ± 1.9^b
Flavor	5.8 ± 1.8^a	5.4 ± 1.8^a	3.5 ± 1.5^b	3.2 ± 1.4^b
Greasy sensation	4.6 ± 1.9^a	4.5 ± 2.1^a	4.1 ± 1.9^a	4.2 ± 2.0^a
Overall acceptability	6.0 ± 1.6^a	5.9 ± 1.6^a	3.9 ± 1.6^b	3.4 ± 1.4^b

Note: Dislike extremely = 1; dislike very much = 2; dislike slightly = 3; neither like nor dislike = 4; like slightly = 5; like very much = 6; like extremely = 7. Data are shown as mean ± standard deviation. Data with different superscript letters within the same row are significant different ($p < 0.05$; $n = 50$).

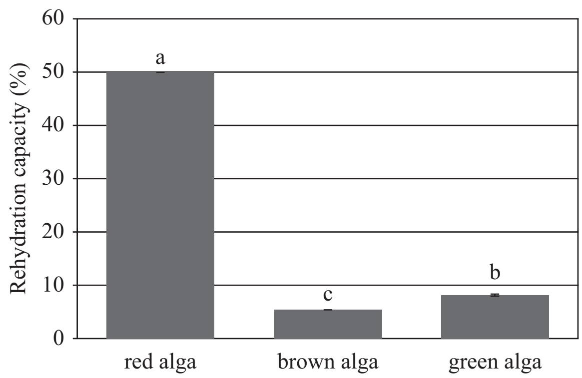


Fig. 2. Rehydration capacity of different algae lees. a-c indicate significant differences between different kinds of algae lees ($p < 0.05$).

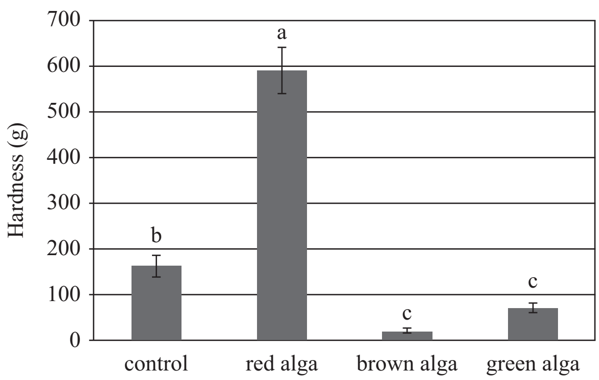
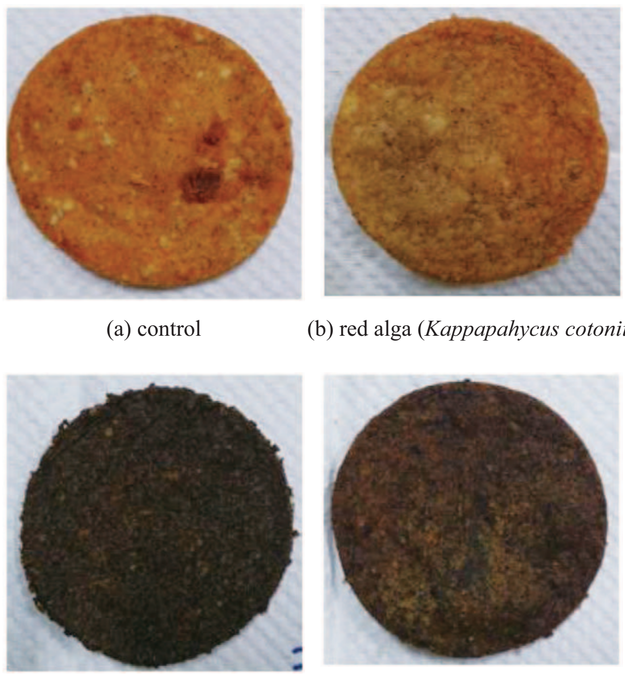


Fig. 3. Hardness of baked potato chips with different algal lees added (2.5%). a-c indicate significant differences between different kinds of baked potato chips ($p < 0.05$).

of the red alga *Kappaphycus contonii* was extremely high (Fig. 2). This might result in more water binding during dough mixing, so the water was absorbed into the tapioca starch and the gelatinized starch form well after baking. The control and green and brown algal lees added groups might not be enough water for starch to gelatinize during baking. This effect might make the red algal lees chips become firmer after baking (Fig. 3) and retaining more moisture (Table 1) than the other treatments and



(a) control (b) red alga (*Kappapahycus cotonii*)

(c) brown alga (*Sargassum cristaefolium*) (d) green alga (Ulva fasciata)

Fig. 4. Photographs of baked potato chips with different algae lees added (2.5%).

the control. In fact, the firmness of baked potato chips with red algal lees was the highest, but the moisture content of chips was in the range of 1.89% to 3.44% after baking (Table 1) with no correlation to water activity. The latter value was always below 0.6 (Fig. 1), which indicated that potato chips with any of the three kinds of algal lees could be stored safely at room temperature under proper packaging conditions.

2. Quality of Baked Potato Chips

The addition of 2.5% brown or green algal lees to the dough led to significantly ($p < 0.05$) decreased hardness of the baked potato chips (Fig. 3). In contrast, adding 2.5% red algal lees was effective in increasing the hardness of the baked potato chips

Table 3. Color values of baked potato chips with different kinds of algal lees added.

	Control	Red alga (*Kappapahycus cotonii*)	Brown alga (*Sargassum cristaefolium*)	Green alga (*Ulva fasciata*)
L	86.78 ± 0.28^a	79.51 ± 0.36^b	40.2 ± 0.09^d	48.97 ± 0.16^c
a	-3.04 ± 0.13^c	1.44 ± 0.15^a	0.34 ± 0.09^b	-4.12 ± 0.03^d
b	44.79 ± 0.12^a	44.17 ± 0.27^b	24.11 ± 0.01^d	29.18 ± 0.13^c
White index	45.03 ± 0.28^a	33.91 ± 0.28^b	15.74 ± 0.17^d	23.91 ± 0.04^c

Note: a-d indicate significant difference between different kinds of potato chips ($p < 0.05$).

(Fig. 3). Overall acceptability scores of baked potato chips containing green or brown algal lees were significantly ($p < 0.05$) lower than those of the control baked potato chips (Table 2) due to their dark color (Fig. 4) and strong seaweed flavor. This indicated that in any commercial product the proportion of green or brown algae lees should be less than 2.5%, although we did not try to determine the precise upper limit to retain palatability. Color and crispness scores for baked potato chips containing 2.5% red algal lees were not significantly ($p > 0.05$) higher than those of the control potato chips. The main problems related to dietary fiber added in the baking of bread are changes in texture of the bread and a significant reduction in loaf volume (Guillon and Champ, 2000); however, the diameter and thickness matched those of the controls, even after baking (Fig. 4).

3. Radical Scavenging Activity of Baked Potato Chips

Estimation of antioxidant activity by scavenging of stable radicals such as the chromogen radical DPPH in inorganic media has been extensively used for the comparison of homogeneous series of antioxidants (Morales et al., 2009). This procedure measures the hydrogen-donating capacity of the target substances, in this case baked potato chip extract with or without three different kinds of algal lees, in a methanolic medium (Morales et al., 2009). A decrease in the DPPH radical concentration of the medium, assayed by its change in color, indicates the extent to which radical-scavenging activity of the potato chips has developed during baking. Radical-scavenging activity expressed as a percentage of reduction of DPPH absorption is shown in Fig. 5. Baked potato chips with red algal lees displayed higher ($p < 0.05$) scavenging activity than those with brown algae lees, but showed no significant difference ($p > 0.05$) compared to the control potato chips.

4. Ferrous Ion Chelating Activity

Baked potato chips with red algal lees showed reasonably good ferrous ion chelating efficacy compared to that of control potato chips. Among all the seaweed lees, the ferrous ion chelating efficacy was not significantly higher ($p > 0.05$) for the baked potato chips with red algae lees added.

5. Chromaticity

There were differences in the color values of baked potato chips with algal lees and control potato chips. Higher L and white index values were found for baked potato chips with red algal lees as compared to those with brown and green algal lees (Table 3). The red value (a) was the highest for the baked potato chips with red algae lees (Table 3), and a difference between the controls and baked potato chips with red algal lees was readily apparent (Table 3 and Fig. 4). Lower b values (greenness) were recorded for baked potato chips with green and brown algal lees than for others, while the lowest was chips with green algal lees. The L, b and white index values were less for baked potato chips with brown algal lees than for the other kinds of chips (Table 3). The surface color of chips with brown and green algal lees were darker than those of the other chips (Fig. 4). The difference in the L, a, b and white index values of algal lees-added chips compared to those of the control was significant (Table 3), which was lighter in color.

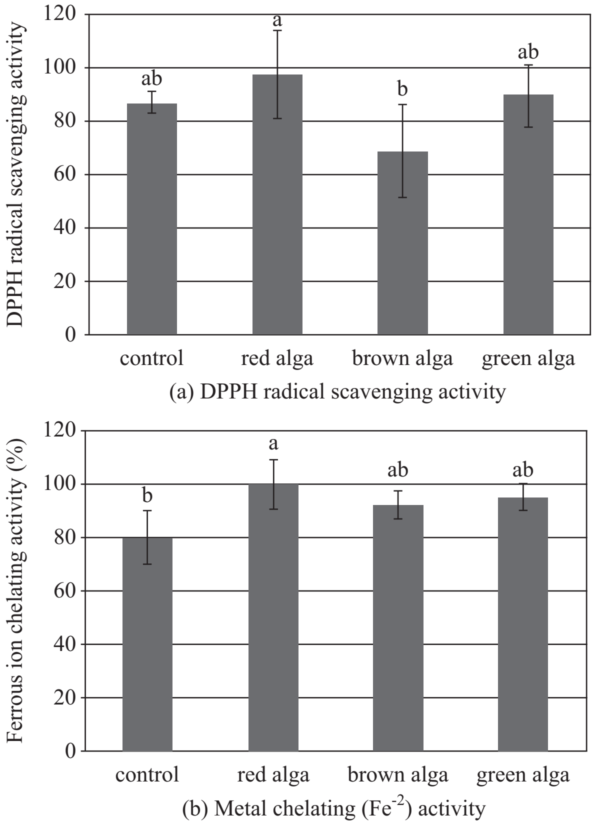


Fig. 5. Antioxidant properties of extracts from baked potato chips with different kinds of algal lees added. a-b indicate significant differences between different kinds of baked potato chips ($p < 0.05$).

6. Sensory Evaluation of Baked Potato Chips

There was no significant difference in the hedonic scores of sensory evaluation between the control and baked potato chips with red algal lees (Table 2). The panelists liked very much the control and also the baked potato chips with red algal lees very much. They detected no difference in greasy sensation between the controls and any algal treatment. The addition of 2.5% green and brown algal lees to the potato chip dough did result in a downgrading of the appearance, uniformity of color, aroma, crispness, flavor and overall score (Table 2). An appropriate lower quantity (< 2.5%) of green or brown algal lees might improve the appearance of the potato chips or even enhanced their flavors, but testing for the optimum concentrations is needs. Addition of red algal lees at a level of 2.5% result in ($p > 0.05$) crispier texture than the control potato chips. The sensory panelists preferred the harder texture and a lighter potato chip color provided by chips containing red algal lees. Of the potato chips with algal lees evaluated in this study, red algal lees also provided the greatest increase in DPPH radical scavenging activity and ferric chelating activity (Fig. 5) and were also acceptable at a dosage of 2.5% according to the sensory evaluation results (Table 2).

IV. CONCLUSION

The results show that red algal lees can be added to potato chips at a 2.5% level to increase their ferrous ion chelating efficacy (not significant difference) without any negative effects on overall acceptability. Addition of algal lees also significantly increased the ash, protein and dietary fiber content of the baked potato chips, but there were no obvious changes in antioxidant activity. Adding red algae lees into potato chips will be a beneficial application for the food industry. Some of the same benefits accrue from the addition of green or brown algal lees, but the sensory trials suggest that a concentration at 2.5% is too high. What level is acceptable remains to be determined. Red algal lees thus appear to be the most promising target for future studies aimed at using algal by-products as supplementary ingredients in baked goods in general. Such industrial use could also help with waste recycling, thereby countering pollution.

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