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Effect of Heat Processing on the physical Properties of the Brown Seaweed (*Ascophyllum nodosum*)

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Original Research Article

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Abstract: There is an increasing demand for natural materials to replaces synthetic additives in the food industry. Seaweeds seem to confer health benefits due to their antioxidant activity because of their specific phenolic compounds which contribute to the total antioxidant activity the food industry, Brown algae provide an excellent source of carotenoids, protein, dietary fibre, proteins and many vitamins, carrageenans extracted from seaweeds are widely used as thickener and stabilizer to improve the texture of cottage cheese, to provide the required viscosity and texture of puddings and dairy desserts, and also it is utilised as binders and stabilizers in the meat-processing industry for the production of hamburgers. The objective of this study was to determine the effect of dry heat processing at, 70, 90, 121 and 200 ^{0}C for 15 and 30 minutes on functional properties such as swelling capacity, water retention and oil retention capacity of the *Ascophyllum nodosum* sample was determined. The present data indicated that the. Swelling capacity of *A nodosum* was slightly increased when it was submitted to heating at 70 ^{0}C, 90 for 15 and 30 min, but decreased at 121 ^{0}C and 200 ^{0}C for 15 and 30 min. Water retention capacity was slightly increased at 70 ^{0}C and 90 ^{0}C for 15 and 30 min. However it was significantly increased at, 121 and 200 ^{0}C for 15 and 30 min. Food processing had no significant effect on *the* oil retention capacity of *A nodosum*. It can be conclude that it is beneficial adding *Ascophyllum nodosum* to food cooked at 70 ^{0}C, 90 as a potential source for the swelling capacity, water retention and oil retention capacity instead of synthetic additives which have harmful effect on health.
Keywords: Brown algae, carotenoids, *Ascophyllum nodosum*, hamburgers, cottage cheese.

INTRODUCTION

Recently scientists extended their hypothesis concerning the seaweeds functions in both the food industry and the medical science. Marine algae are rich bioactive substances that are not usually present in terrestrial plants, and there are many scientific papers that have been provided huge evidence about their effects. For example Yuan and Walsh [1] pointed out that extract of edible seaweeds prevent oxidation and proliferation of food. Also brown seaweeds have Physical properties such as solubility and viscosity are altered by the effect of heat during processing [2]. Alginates, an extract of brown algae are soluble in water-miscible solvents such as alcohols and ketones. Its viscosity increases with the concentration of alginate used and decreases with increasing the heat due to the presence of the pure sodium alginate solution and can be kept at room temperature for several months without distinct change in viscosity. All alginate solutions will depolymerize with increasing temperature. Alginate solutions are stable in the pH range 5.5 – 10 at room temperature for a long time, but will form the gel below pH 5.5 [3]. In the food industry, carrageenan's extracted from seaweeds are widely used as thickener and stabilizer to improve the texture of cottage cheese, to provide the required viscosity and texture of puddings and dairy desserts, and also it is utilised as binders and stabilizers in the meat-processing industry for the production of hamburgers, patties and sausages [4].The total market of carrageenans has been estimated as US $300 million/year in food manufacturing [4].

In China and Japan people established the brown alga Hizikia fusiformis as vegetable. This seaweed has a significant therapeutic feature due to their oxidative compounds [5, 6]. The oxidative process in some kinds of foods such as meat leads to decomposition of proteins and lipids which result in deterioration in texture, flavour and colour of fresh retail meat [7]. As a result, public attention to natural antioxidants has been increasing during the last years, and there is growing knowledge in the recognition of novel natural antioxidants that would serve as substitutes to the synthetic antioxidants [8, 9]. Numerous studies have been conducted on physical properties in terrestrial plants and their application in

food schemes. Also aquatic plants such as seaweeds or other microalgae have an importance function as potential sources for water and oil retention [10, 11].

Aim of study

The aim of the present research was to

Study the effect of processing on the physical properties of *Ascophyllum nodosum*, such as swelling capacity, water retention capacity and oil retention capacity**,** and moisture.

METHODS

Determination of swelling capacity *of Ascophyllum nodosum* was based on the method by Robertson *et al*. [12]. Sample (1g) was mixed with 10 mL of 0.02% aqueous sodium azide in a 10 mL measuring cylinder (0.1 mL graduation). Then the solution was mixed gently to avoid any trapped air bubbles and left for 18 h, at room temperature on the level surface overnight to allow the sample to settle. The occupied volume (mL) of the sample was measured and SC was expressed as mL / g of dry seaweed**.**

Determination of Water Retention Capacity (WRC) of Ascophyllum nodosum

The water retention capacity was measured according to Robertson *et al*. [12] method. Sample (0.5 g dry weight) was hydrated in 30 mL distilled water, containing 0.02% azide (0.02 g of sodium azide dissolved in 100 ml distilled water), in a centrifuge tube at room temperature. The sample was dispersed with gentle stirring. After equilibration (18 h), samples were centrifuged (Hermle®, model Z36Hk, Germany) at 2990g rcf for 20 minutes at 15 ^{0}C. The supernatant was removed and then the solid was weighted. WRC (g/g) was calculated according this formula WRC = Residue fresh weight- residue dry weight/ Residue dry weight [12].

Determination of Oil Retention Capacity (ORC) of Ascophyllum nodosum Hydration with Oil

The oil retention capacity was measured according to Robertson *et al.* [12] method. Sample (0.5 g dry weight) was hydrated in 30 mL olive oil (Extra Virgin Olive Oil, Filippo Berio® Company, Packed in Italy), in a centrifuge tube at room temperature. The sample was dispersed with gentle stirring. After equilibration (18 h), samples were centrifuged in (Hermle®, model Z36Hk, Germany) at 2990g rcf for 20 minutes at 15 ^{0}C. The supernatant was removed and then the solid was weighted. ORC (g/g) was calculated according this formula: ORC = Residue fresh weight- residue dry weight/ Residue dry weight. These methods for determination of seaweed physical properties were simple, and have been commonly used. As The hydrated sample was free from any bacterial growth due to presence of sodium azide. As well, the sample was soaked for enough time (18 hrs) to be settled down and hydrated [12].

Determination of Seaweed Moisture Content

The moisture content of dry unheated sample was measured by infrared moisture balance system (Kern, model HS 0.824, Germany).

Statistical Analysis

All analysis was carried out in triplicate, and data were expressed as the means and standard deviation (SD). The excel program for PC was used for data analysis. Student T Test) was used to get level of significant difference. Where $p<0.05$, Student T Test is a statistical procedure that determines if the difference found between the control and each heated sample is due to the treatment or if it is due to random chance

RESULS

Swelling Capacity

Swelling capacity (SC) was expressed in ml/g dry seaweed weigh. The highest volume was occupied by heated samples. The heating process made significant differences in the samples' swelling capacity when the control was compared with each heated seaweed sample. For example, the sample heated at 70 ^{0}C for 15 min had an SC = 4.6 ml/g; the sample heated at 70 ^{0}C for 30 min had an SC of 4.9 ml/g; 90 ^{0}C, 15 min, SC = 4.6 ml/g; 90 ^{0}C, 30 min, SC =4.5 ml/g ; 121 ^{0}C, 15 min, SC = 4.6 ml/g,; and 121 ^{0}C, 30 min, SC = 3.8 ml/g, and each had a P value < 0.001. However, there were no significant differences in 200 ^{0}C, 15 min (4.1 ml/g), 200 ^{0}C, 30 (4.1 ml/g), where the P value > 0.05. Thus, the heating-process had no significant effect on samples which were heated at 200 ^{0}C for 15 and 30mins, whereas the swelling capacity increased significantly in the rest of the samples, except in the sample at 121 ^{0}C, 30 min where it decreased (as shown in Figure 1).

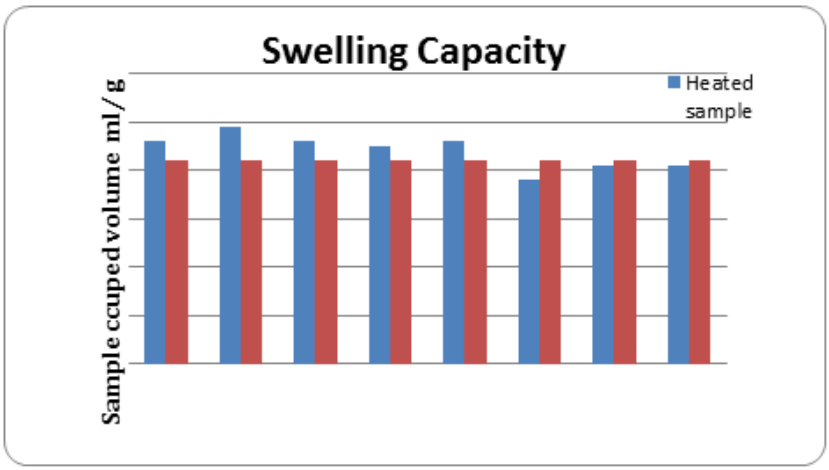

Fig-1: The Swelling Capacity of the Control and Heated Sample in ml/g DW
The data represents the average swelling capacity of the control and heated samples

Water Retention Capacity

Water Retention Capacity (WRC) was expressed as g oil/ g dry seaweed. The highest water capacity value was in the sample heated at 200, 30 min (3.7g/g) followed by 200 ^{0}C, 15 min (3.1 g/g), 121 ^{0}C, 30 min, 121 ^{0}C, 15 min and 70 ^{0}C, 30 min which had the same WRC (2.3 g/g) and 70 ^{0}C, 15 min (2.2 g/g). On the other hand the lowest WRC was in the control sample (1.5 g/g). It seems that the heating process had a positive effect on the WRC of the tested samples (as seen in Figure 2). The WRC of all samples was calculated according to this formula: WRC g/g = (Residue fresh weight- residue dry weight/ Residue dry weight).

The difference between the Water Retention Capacity of each these of samples: 90 ^{0}C, 15 min (2.4 g/g), 90 ^{0}C, 30 min (2.3 g/g), 121^{0}C, 15 min (2.5 g/g), 121 ^{0}C, 30 min(2.6 g/g), 200 0C, 15 min(3.1 g/g), 200 0C, 30 min200 0C, 30 (3.8 g/g) and the control was significant where the P value was < 0.001. However, there was no significant difference between the control and the sample at 70 ^{0}C, 15 min, and the control and the sample at 70 ^{0}C, 30 min where the P value was > 0.05. This means that the water retention Capacity of seaweed was not affected by heating at 70 ^{0}C for15 and 30 min, but there was an increase in the rest of the samples that were heated to more than 70 ^{0}C.

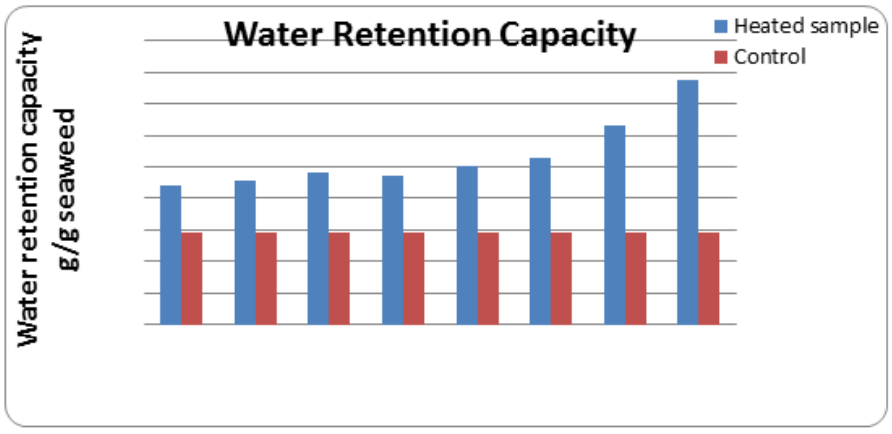

Fig-2: Water Retention Capacity of the control and Heated Samples in g/g DW

Oil Retention Capacity

The highest Oil Retention Capacity (g oil/ g dry seaweed) was in the sample heated at 70 ^{0}C for 15 min (2.3 g/g), followed by the control (2 g/g). Samples heated at 90 ^{0}C, 30 min, 121 ^{0}C, 15 min, 121 ^{0}C, 30, 200 ^{0}C, 15 min had the same Swelling Capacity (1.9 g/g). The lowest ORC was in the samples heated at 70 ^{0}C, 30 min and 200 ^{0}C, 30min (1.8 g/g in both samples) as shown in (Figure 3).

The ORC of all samples was calculated according to this formula: ORC g/g = (Residue fresh weight-residue dry weight/ Residue dry weight).

On the basis of our results it seems that the thermal heating at different temperatures and times had no significant effect on the ORC of all the heated samples except at 70 ^{0}C, 15 min (with an ORC of 2.3 g/g) where the ORC was slightly increased by 0.3 g/g. However, the WRC of all the heated samples was significantly increased when the heating temperature

increase. More-over, the SC of all the heated samples slightly increased with thermal treatment.

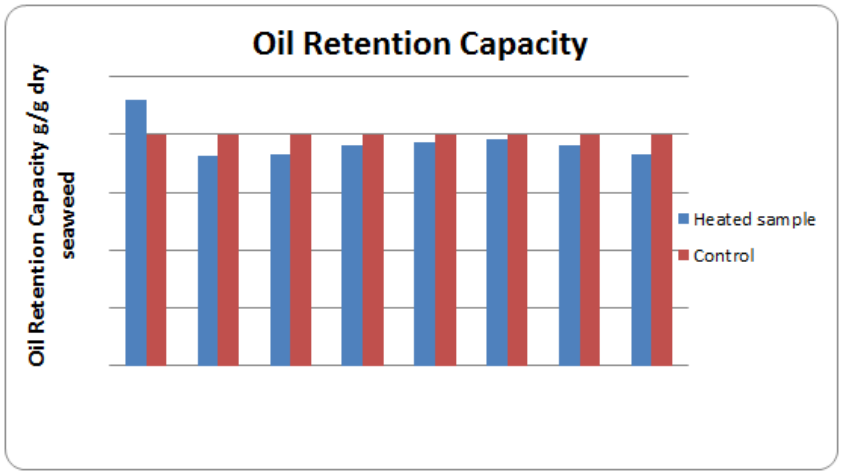

Fig-3: The Oil Retention Capacity of the Control and Heated Samples in g/g Dry Weight

On the basis of our results there were no significance differences between the unheated sample and each one of the heated samples where the P value was > 0.05. On the other hand, there was a significant difference between the unheated sample and the heated samples where the highest ORC value was 2.3 g/g at 70 ^{0}C, 15 min (as shown in Figure 4, and Table 1).

Table-3.3: Physicochemical properties of control and heated samples

Seaweed sample	*Swelling capacity (ml/g dry wt)*	*Water capacity (g/g dry wt)*	*Oil retention capacity (g/g dry wt)*
Control	4.2±0.05	1.5±0.05	2.0±0.14
70C,15min	4.6±0.02	2.2±0.01	2.3±077
70C,30min	4.9±2.00	2.3±0.64	1.8±0.04
90C,15min	4.6±2.00	2.3±0.06	1.8+0.12
90C,30min	4.5±0.06	2.6±0.01	1.9±0.15
121C,15m	4.6±0.05	2.5±0.06	1.9±0.11
121C,30m	3.8±2.00	2.6±0.06	1.9±0.28
200C,15m	4.1±0.05	3.2±0.06	1.9±0.14
200C,30m	4.1±0.08	3.9±0.06	1.8±0.06

Mean value of triplicate determinations ± standard deviation of three experiments

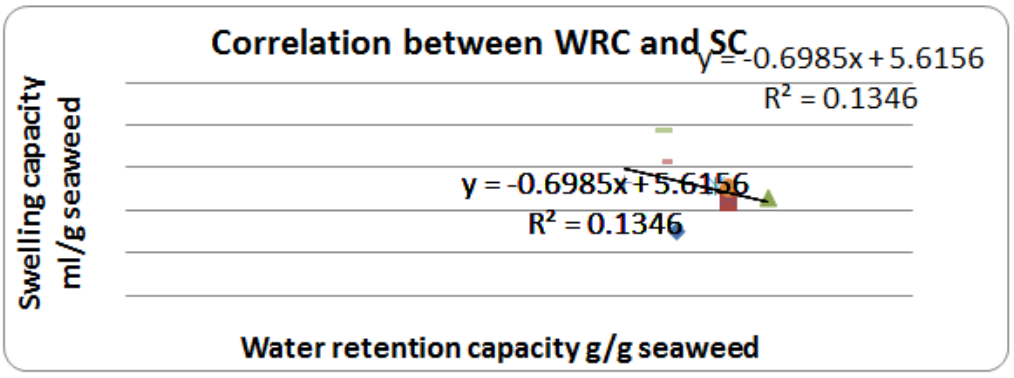

Fig-4: showed very little correlation between WRC and SC.

DISSCUSSON

Physical Properties of Seaweed

Fibre has the ability to absorb and hold water. From these points dietary fibre's resistance to digestion provides bulk to faeces, holding water. Seaweeds possess these potential properties which allow them to be used in food technology to provide low-calorie food which might be important in body-weight control,

reduction of hyperlipidemia as well as in prevention of cardiovascular diseases

[13].All species of the brown seaweeds have been selected as a good source of dietary fibre. However they are different in their soluble fibre contents. Seaweeds have an excellent nutritive value, because of their protein, polysaccharide, mineral and vitamin contents. Also their cell wall includes high levels of non-digestible polysaccharide which makes them a rich source of dietary fibre (0.33-0.5 g.g–1, dry weight basis) [14]. Total dietary fibre content of the main edible seaweeds ranges between 25%-75% (on a dry weight basis).

Swelling Capacity

Swelling Capacity was expressed in ml/g dry seaweed weight. In our results we found that, the highest volume was occupied by heated samples. It seems that the Swelling Capacity of tested samples was increased by the heating process in the sample at 70 ^{0}C, 30 min (4.9 ml/g), followed by those at 70 ^{0}C, 15 min, 90 ^{0}C, 15 min, 121 ^{0}C, 15 min which occupied the same volume (4.6 ml/g). However it decreased significantly at 121^{0}C, 30 min (3.8 ml/g), 200 ^{0}C, 15 and 200 ^{0}C 30 min1.4 ml/g), compared with the control's Swelling Capacity(4.2 ml/g) (as in Figure 3.10 and Table 3.3).

The heating process made significant differences in the samples' Swelling Capacity when the control was compared with heated seaweed samples that were heated at 70 ^{0}C, 15 min, 70 ^{0}C, 30min, 90 ^{0}C, 15min, 90 ^{0}C, 30 min, 121 ^{0}C, 15min, as the P value was < 0.001. However, there were no significant differences in the samples at 121^{0}C, 30min, 200 ^{0}C, 15, 200 ^{0}C, 30 where the P value was > 0.05. Thus, the heating process had no significant effect on the Swelling Capacity of the samples which were heated at 121^{0}C, 30min, and 200 ^{0}C 30 min whereas Swelling Capacity increased in the rest significantly.

Therefore, according to the present study, Swelling Capacity increased in samples which were heated at 70 ^{0}C, 90 ^{0}C and 121^{0}C. Nevertheless it was reduced where samples were heated above 121^{0}C. This agreed with recent research by Rupérez *et al.*, [14] which concluded that brown seaweeds have a high Swelling Capacity. These properties could be related to their insoluble fibre content, whereas others attributed it to the high uronic acid contents of soluble fractions of dietary fibre [15]. A previous study which was conducted by [16]. Showed that apple AIS water Swelling Capacity totally depended on the method of drying samples: the samples that were freeze-dried had a Swelling Capacity of about 20 ml/g. However when they were oven-dried, swelling was less than 10 ml/g. This was in complete agreement with our results, especially where our samples were oven-dried. Their Swelling Capacity range was 4.1-4.9 g/g and it not exceeds 10 ml/g.

In contrast, Mei, X *et al*., [17] determined the Swelling Capacity in different varieties of sweet potato and the range was 8.11-12.56 ml/g DW. This was higher than the swelling capacity of the control and heated samples in our results. Similarly cocoa, apple and citrus had SC of 6.52, 7.42 and 10.45 ml/g respectively [18]. Moreover, Figuerola *et al.* [19] found that the Swelling Capacity range of orange, grape, lemon and apple was 6.11-9.19 ml/g. Raghavendra *et al*. [20] compared the Swelling Capacity of ten available dietary fibres (oat bran, citrus, pea hull, bran, pea, wheat, fruits and fibre, apple and coconut) and they concluded oat bran had the lowest swelling capacity and coconut the highest (5.3 and 20 ml/g respectively). Among *Ascophyllum nodosum*, all these plant sources had high SC values compared with that of the tested samples. This could be due to different possibilities as following:

The determination of physical properties is based on the methods used for sample preparation and extraction such as drying, temperature as well as the particle size of sample [14]. T Yu *et al*. [1] found that bacterial fermentation increased the water and oil retention capacity of roasted peanut. This explains using 0.02% sodium azide in our study to avoid bacterial fermentation of samples.

Water Retention Capacity

Water Retention Capacity was expressed as g water/ g dry seaweed. The highest WRC values were in the sample at 200 ^{0}C, 30 (3.8 g/g), followed by those at 200 ^{0}C, 15 min (3.1 g/g), 121 ^{0}C, 30 min (2.6 g/g), 121 ^{0}C, 15 min (2.5 g/g), 90 ^{0}C, 15 min (2.4 g/g). 90 ^{0}C, 30 min and 70 ^{0}C, 30 min had the same WRC (2.3 g/g). The sample at 70 ^{0}C, 15 min had a WRC of 2.2 g/g. However the lowest WRC was in the control sample (1.5 g/g) as shown in Figure 3.11, Table 3.3.

The differences between the WRC of each of these samples at 90 ^{0}C, 15 min, 90 ^{0}C, 30 min, 121^{0}C, 15 min, 121 ^{0}C, 30 min, 200 ^{0}C, 15 min, and 200 ^{0}C, 30 min and the control were significant, as the P value was < 0.001. But there were no significant differences between the control and the sample at 70 ^{0}C, 15 min, and the control and the sample at 70 ^{0}C, 30 min. This means that the WRC of seaweed is not affected by heating at 70 ^{0}C for 15 and 30 min, but there is a significant increase in that of the rest of samples that were heated to more than 70 ^{0}C.

It clear that there was a positive correlation between thermal treatment and the Water Retention Capacity (as in Figure 3.8, and Table 3.8). This disagrees with a previous study on the physical properties of cauliflower by Femenia *et al*. [15]. They concluded that the WRC of cauliflower was reduced significantly from 12.8 to 5.7 g/g when it was dried at 75 °C for dehydration. The Water Retention Capacity values of the tested samples ranged from 1.5-3.8 g/g.

These results were in disagreement with previous research that pointed out that *Wakame* brown seaweeds had a WRC ranging from 19 to 44 g/g dry seaweed [21]. The WRC of sweet potato was 3,54g/g [17]. Raghavendra *et al*. [20] determined that the Swelling Capacity of different dietary fibre sources was significantly different; they found that citrus and coconut had the highest WRC and wheat bran had the lowest (7 g/g and 1.9 g/g respectively). Nevertheless it is difficult to compare WRC with other studies, because they were based on a variety of experimental conditions such as temperature, time, centrifugation, sample preparation and particle size treatment as well as pH [15, 14]. Acidic pH lowers the WRC of seaweed [22].Also most of these studies were conducted on plants rich in pectin. Fibre with high pectin content had high WRC [23]. This explains idea that seaweed had a lower WRC compared with various plants.

Oil Retention Capacity

The highest oil-holding capacity (g oil/ g dry seaweed) was in the sample at 70 ^{0}C, 15 min (2.3 g/g), followed by the control (2 g/g); and samples at 90 ^{0}C, 30 min, 121 ^{0}C, 15 min, 121 ^{0}C, 30, and 200 ^{0}C, and 15 min had the same ORC (1.9 g/g). The lowest ORC was in the sample at 70 ^{0}C, 30 min and at 200 ^{0}C, 30min, (1.8 g/g),) as shown in Figure 3.9. Thermal treatment has a positive effect on ORC in the 70 ^{0}C, 15 min sample. However, it decreased in the rest of the tested samples (as in Figure 3.9, and Table 3.8).

On the basis of our results there were no significance differences between unheated samples and each one of the heated samples where the P value was >0.05. However, there were differences within heated samples, and the highest ORC value was in the sample at 70 ^{0}C, 15 min

All ORC values of heated samples decreased except in the 70 ^{0}C, 15 min sample where it increased. This decrease was in agreement with a recent study which showed that WRC and ORC were reduced in roasted peanut flour through protein denaturation by high temperature which exposed the hydrophobic group. This clarifies the decreased WRC. The Oil Retention Capacity of peanut flour was reduced as a result of irreversible denaturation caused by thermal treatment at 175 C, which may destroy both the hydrophilic and hydrophobic sites of peanut [1]. The range of ORC of the sample in this current test was 1.8 to 2.3g/g. Recent research conducted by Elleuch *et al*., [24] showed ORC was 1.9-2.5 which agrees with the result of the tested samples. Also the current results are in agreement with Figuerola [19] who pointed out that sweet potato had an ORC range of 1.81 to 2.6 g/g. However there was disagreement with the ORC values of wheat, pea, carrot, apple and sugar beet which were 1.3,0.9, 1.3,1.2, and1.5 g/g respectively [25]. This might due to variation in granule- size, since the ORC of seaweed increased when their particle size was small [26]. This was the same as what was used in our study (fine granular powder). However, it could also be influenced by the charge density and hydrophilic nature of individual particles [28].

Correlation between Water Retention Capacity and Swelling Capacity

Suzuki *et al*. [21] found that a correlation between WRC and SC has previously been observed and it was very high (r=0.961). This disagrees with the present study where r =0.13 (Figure 3.13). From this point we may conclude that the results do not seem to agree with what was previously mentioned about the correlation between water retention and swelling capacity, because the WRC of all the heated samples was increased by heating. However, SC was increased in the samples at 70 ^{0}C, 30 min, 70 ^{0}C, 15 min, 90 ^{0}C, 15 min, and 121 ^{0}C, 15 min, but it decreased in the rest of samples. Furthermore, there are some points of discrepancy with little information from literature reviews on this current topic. Most of the data in the literature which are available concern the screening of the water retention capacity and swelling capacity in raw seaweeds and there is little information about the effect of heating on these properties.

CONCLUSION

This study dealt with the effect of heat processing on total phenolic content, antioxidant activity and the physical properties of *Ascophyllum nodosum* at different food processing temperatures. Heating processes at 70 ^{0}C and 90 ^{0}C for 15 and 30 min had no significant effect on *Ascophyllum nodosum* total phenol content. However TPC was significantly decreased at 121^{0}C and 200 ^{0}C for 15 and 30 min. Therefore it is beneficial to add *Ascophyllum nodosum* to food that is processed at 70 ^{0}C, 90 ^{0}C, for 15 and 30 in order to increase or maintain the TPC. Scavenging antioxidant activity was significantly reduced by cooking processes at 200 ^{0}C for 15 and 30 min, and it was not affected at 70 ^{0}C, 90 ^{0}C, and 121 ^{0}C for 15 and 30 min. So it is worth adding *A. nodosum* to food cooked at these temperatures but not adding it to food cooked at 200 ^{0}C. However all these cooking degrees reduced the ferric-reducing antioxidant power? The Swelling Capacity of *A. Nodosum* significantly increased when it was submitted to heating at 70 ^{0}C and 90 for 15 and 30 min, but it was decreased at 121 ^{0}C and 200 ^{0}C for 15 and 30 min. The Water Retention Capacity of samples at 70 ^{0}C for 15 and 30 min was not significantly changed. However it significantly increased at 90 ^{0}C, 121 ^{0}C, and 200 ^{0}C for 15 and 30 min. Food processing had no significant effect on *A. Nodosum* Oil Retention Capacity. Therefore, to maintain or increase and avoid any loss of TPC, antioxidants, SC, WRC and ORC at the same time, it is worth adding *A. Nodosum* to food cooked at 70 ^{0}C and 90 ^{0}C and not worth adding it to food cooked at 121^{0}C and 200 ^{0}C

RECOMMENDATIONS

- The findings of our study provided helpful information for further studies which should be carried out in order to confirm if the heat processing can maintain and enhance TPC, AOA, SC, WRC and ORC.
- *A. nodosum* had excellent phenol content and antioxidant capacity. Furthermore it should be used extensively in Food Technology to support health and minimize the risk of modern life disease.
- The Swelling Capacity, Water Retention Capacity and Oil Retention Capacity of *A. nodosum* could be useful for its development as a natural functional additive in the food industry to enhance the viscosity and texture of food products.

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