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Investigation of influence of pre-treatment and low-temperature on drying kinetics, sorption properties, shrinkage and color of brown seaweeds (Saccharina Latissima)

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Abstract

Drying kinetics of Saccharina latissima (raw and blanched) at low temperatures (10.0, 25.0 and 38.0 °C) was studied. The effective moisture diffusivity coefficient varied due to temperature alterations in the range between 1.4 and 4.5 10^{-10} m^2/s for raw and 0.91 and 2.56 10^{-10} m^2/s for blanched seaweeds. Significant changes in structural properties and chemical composition resulted in a much longer drying time of blanched seaweeds, when compared with raw. Drying temperature of 38.0 °C resulted in more brown color, when compared with other samples. Sorption characteristics of dried raw seaweeds depended on salt content and showed high accumulation of moisture at relative humidity of air of 80.0 %. The blanched seaweeds showed linear accumulation of moisture within increasing of relative humidity of drying air from 20.0 to 80.0 %, but high level of hysteresis was determined between sorption and desorption isotherms. The shrinkage development within dewatering of blanched and raw samples was also studied.

Keywords: *brown seaweeds, drying kinetics, sorption isotherms, color*

1. Introduction

As much as 36 % (30 million tons of total harvest) of seaweed is used as a direct food source[1]. The main representatives of the food-grade seaweeds are: Laminaria japonica (Kombu) and Saccharina latissima (Royal Kombu) [2], which are mostly produced and consumed inAsia. At the same time the key advantage (and the main potential) of the seaweed industry in Europe is its independence from three main resources, that limit conventional agriculture: land, water and fertilizers [3]. The brown seaweeds Saccharina Latissima are cultivated now in Norway with the aim to produce food-grade products. However, the harvesting season is short and raw material has a very low stability. Thus, the effective stabilization method is required.

Drying is the common way to preserve food products like seaweed and most of the seaweeds are sold in a dried form [4]. Solar and natural drying of seaweeds is a cost-effective method. At the same time climate conditions can result in a high final moisture content in dried porduct[5] due to high moisture absorption ability [6], aslo, the process 5 or 7 days [7] and this is not a feasible and safe to apply the method for food graded seaweeds for European market. The demand for traceability and safety appears, when the drying process is used for food production. Drying of seaweeds for long time and/or at high temperature influences negatively on their carbohydrates, amino acid composition and vitamin content [8]. The resent study of Saccharina Latissima revealed that decreasing of the drying temperatures results in the increasing of quality[9]

The task of this study was the determination of the main process dependencies for the low temperature drying of Saccharina Latissima after frozen storage with the aim of implementation this knowledge into the sustainable drying process.

2. Materials and Methods

2.1 Characterization of raw material

The brown algae *Saccharina latissima*, which is commonly referred as kelp (Sugar kelp or kombu) was used for the experiments. The seaweeds was cultivated for one year in an aquaculture farm, which is situated in Sør-Trøndelag (Norway). Harvesting season was 3 days in May 2016 to maintain the best quality of the seaweeds and avoid high amount of biofouling. The seaweed was harvested into nets (75-150 kg). The nets were buffered in the seawater at the farm for up to 1 weeks before processing. Then the seaweeds were sorted to remove seaweed of a bad quality. Afterwards, the seaweed was weighed out and packed inside vacuum bags with high barrier properties (2.0 kg each). Freezing was at –46 °C for 20-25 min until the temperature inside the bag reached -18.0 °C. The bags were packed in cardboard boxes, put on pallets and placed in freeze storage at -18 °C. The freezing process was applied to stabilize the product, because harvesting season is short (few days) and high amount of biomass is difficult to process before deterioration will start. Chemical composition of the aquaculture seaweeds is given in the Table 1.

Table 1. Chemical composition of Saccharina latissima at harvesting season (analysis performed by accredited analytical laboratory Kystlab preBIO, Frøya, Norway).

Chemical composition	***%, d.b.***	***Minerals , mg/kg d.b.***	
Proteins	11.2	Potassium	84000
Fats	2.9	Sodium	52000
Carbohydrates	55.3	Calcium	10000
Incl. Dietary fiber	46.6	Magnesium	7500
Ash	37.9	Sulfur	7300
Incl. Salt (NaCl)	14.6	Iodine	3670
Water	900.0	Phosphrus	1700

2.2 Experiment description

The frozen seaweeds were divided into two groups: one was blanched seaweeds another group was raw seaweeds without any processing. Frozen seaweeds were defrosted at +5.0 °C in refrigeration cabin to avoid significant degradation of tissues. The blanching took place in a boiling water (100.0 ºC) for 1.0 min. The balnched seaweeds were immediately cooled in water (5.0 °C). The drying took place on shelves in drying chamber with a closed loop air circulation. The following parameters were varied during drying experiments: air temperature: 10, 25 and 38 ºC; amount of seaweed's layers: 1 layer, 2 and 3. The seaweeds were placed in a drying chamber on shelves parallel to the air flow. Relative humidity of drying air for all cases was 16.0 ±4.0 %. Drying air velocity 1.5±0.5 m/s. The drying process was stopped when the moisture content was in the range between 20.0 and 10.0% d.b.

2.3 Determination of drying kinetics

The drying behaviors were modelled using Newton model. The drying behavior itself was characericed via determination of the effective moisture diffusivity. This material property was derived from the drying kinetics via analytical solution of the Fick's second law of diffusion (infinite slab).

2.4 Determination of sorption and desorption properties at different temperatures

Sorption isotherms were determined for dried balnched and dried raw seaweeds at 10.0, 25.0 and 38.0 °C. Desorption properties were determined by drying of raw seaweeds at 25.0 °C 20.0 % RH.

2.5 Determination of color

Color was analyzed with the assistance of ColorFlex EZ Spectrophotometer (HunterLab, USA) using CIE L*C*h* scale. The lightness L* varies from black (L*=0) to perfect white (L*=100). The chromaticity C* reflects the colorfulness; when C*=0, the object is considered to be colorless. Hue is an attribute of a visual sensation, according to which an area appears be similar to one of the perceived colours or to a combination of two of them. It is measured in degrees from 0 to 360°, rose (h*=0°), yellow (h*=90°), green-blue (h*=180°), and blue-violet (h*=270°).

2.6 Statistical analysis

The analysis of variance (ANOVA: single test and two-factor test with replication) was applied to analyze the obtained data. The difference was considered significant at $p<0.05$. All the experimental points were done in six parallels, except of desorption isotherm determination, where each point represents a single experiment. A regression analysis was done with a software DataFit 8.1 program (Oakdale Engineering).

3. Results and Discussion

3.1. Influence of pretreatment and drying modes on color of seaweeds

The blanching process alternated the lightness (L*), chrominance (C), and hue (h) of the seaweeds ($p<0.05$). The typical brown-olive color (by human eye perception) of the seaweeds visually changed to green, this was reflected by increasing of hue by 12º and alteration of chrominance by 71.0 %, Table 2. The lightness of dried raw samples were significantly higher when compared with dried blanched ($p<0.05$). This might be possible due to deposits of salts and other water soluble compounds (for example, mannitol) on the surface of the dried blades of Saccharina latissima, which created a layer on surface with high reflective properties. Chrominance of dried raw seaweeds was also higher ($p<0.05$). Some interesting observations were found regarding the influence of temperature on the hue-value of the dried seaweeds. The drying temperature of 38.0 °C resulted in a slight decreasing of the hue-value, so the color became more “orange (brown)” (in terms of L*C*h* color space), while the seaweeds dried at 10.0 °C showed more “yellow-green” color. This was valid both for raw and blanched seaweeds. One of the possible explanation may be a higher oxidation rate of the pigments by oxygen at a higher temperatures [10].

Table 2. Color parameters of raw and blanched seaweeds before and after drying

Type of seaweeds	**Before drying (Color parameters)**								
	L*, (-)		**C, (-)**		**h,º**	**a*, (-)**		**b*, (-)**	
Raw seaweeds	9.78 (0.96)		8.08 (1.97)		80.23 (1.45)	1.39 (0.43)		7.96 (1.94)	
Blanched seaweeds	11.54 (1.29)		13.84 (1.63)		92.00 (4.04)	-0.13 (1.25)		14.74 (1.39)	
	After drying (Color parameters)								
	L*, (-)			**C, (-)**			**H,º**		
	Temperature, °C								
	38.0	**25.0**	**10.0**	**38.0**	**25.0**	**10.0**	**38.0**	**25.0**	**10.0**
Blanched seaweeds	23.1^{a}	23.7^{a}	23.83^{a}	6.4^{c}	5.76^{c}	6.59^{c}	81.39^{e}	82.85^{e}	86.86^{f}
	(1.54)	(2.19)	(1.23)	(2.84)	(1.89)	(1.32)	(5.66)	(4.57)	(3.3)
Raw seaweeds	25.86^{b}	27.25^{b}	27.91	8.71^{d}	8.39^{d}	8.42^{d}	83.39^{e}	86.00^{f}	86.73^{f}
	(1.12)	(2.78)	(2.46)	(1.33)	(1.02)	(1.09)	(3.07)	(2.53)	(3.03)

3.2 Sorption-desorption characteristics of Saccharina latissima

The dried raw and blanched seaweeds behave differently during absorption of moisture from the ambient air (Fig. 1). Dried blanched seaweeds showed higher accumulation of moisture at low relative humidity of air (from 20.0 to 40.0 % RH) for all the investigated samples, when compared with raw seaweeds ($p<0.05$). While, the trend was changed at 60.0 % RH. Further increasing of the relative humidity in the climate chamber to 80.0 % resulted in a sharp alteration of moisture content in dried raw seaweeds for all the investigated temperatures ($p<0.05$), while dried blanched seaweeds showed almost linear trend of moisture increasing in the range of RH between 20.0 and 80.0 %. The temperature variation between 10.0 and 38.0 °C did not influence on the sorption characteristic of the blanched seaweeds.

The similar behavior was observed by Sappati et al., [11] studied the sorption isotherms of Saccharina latissima at 20.0 °C. The sharp increasing of the equilibrium moisture content of raw seaweeds at 80.0 % and relatively low water absorbance at RH below 60.0 % can be explained by hygroscopic point of salts, which occupy the significant share among other compounds. For example, hygroscopic point of NaCl appears at 75.5 % RH at 25.0 °C, KCl at 82.0 % RH. The salt concentration in raw seaweeds was determined at 14.4 % d.b., while blanched seaweeds were almost salt-free (below 0.5 % d.b). Desorption isotherms were determined at 25.0 °C and compared with sorption profiles at the same temperature. It is interesting to note, that hysteresis phenomena was relatively small for raw seaweeds, while blanched seaweeds showed a significant change in structural properties during drying. It may happens due to freezing and blanching process when the cell membranes were broken and water soluble compounds were easily washed out and replaced by a free water. Thus, significant irreversible shrinkage appears during drying process of blanched seaweeds.

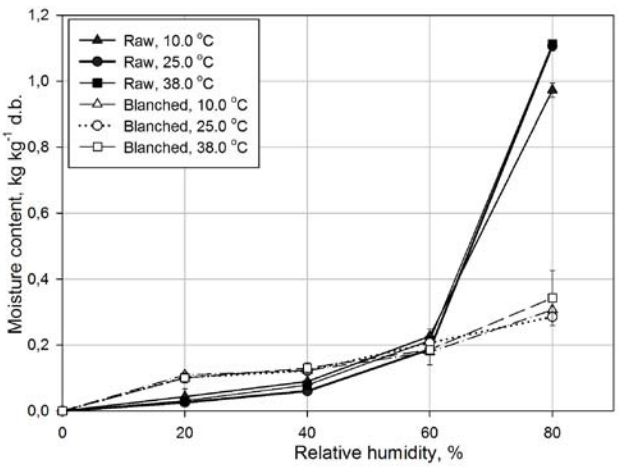

Figure 1. Sorption characteristics of Saccharina Latissima

3.3 Shrinkage of raw and blanched seaweeds during dewatering

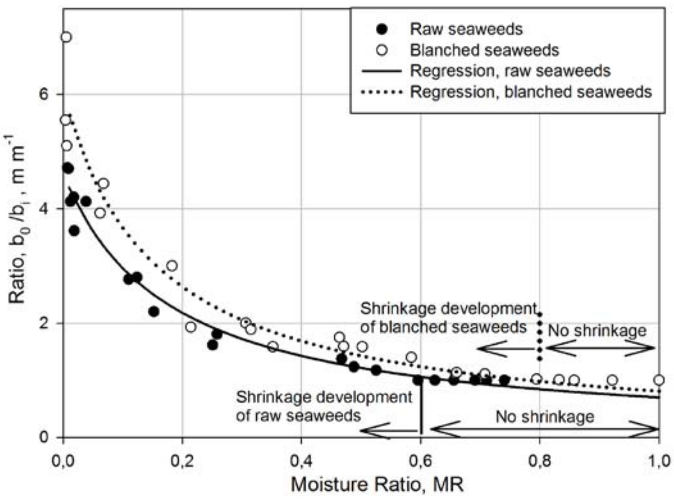

Figure 2. Shrinkage of raw and blanched seaweeds during drying

The drying processes resulted in a significant reduction of blade thickness for raw and blanched seaweeds, Fig. 2, while surface area reduced only by 20.0..25.0 %.

The thickness reductions was much more developed for blanched blades, when compared with raw samples ($p<0.05$). Also, raw seaweeds retained their thickness much longer during dewatering when compared with blanched. The first traces of the thickness decreasing were detected at MR of 0.6 and 0.8 at 25.0 °C for raw and blanched seaweeds respectively.

3.4 Drying kinetics of seaweeds

The drying kinetics was investigated for raw and blanched seaweeds. The raw seaweeds showed initial moisture content at 900.0 (50.0) % d.b. Tthe moisture content of the blanched seaweeds was found at 2079.0 (100.0) % d.b. Dehydration of raw seaweeds was much faster, when compared with blanched. This can be explained by the higher moisture content of blanched seaweeds and also may be linked with the changes of their structure after blanching. The increasing of temperature accelerated the dewatering of the seaweeds both raw and blanched, and the highest dewatering rate was observed for 38.0 ºC.

Newton model was implemented to obtain the regression equations for all the drying temperatures (R^2>0.98; Prob(F)<0.000014; F(Ratio) >700). The empirical drying coefficient k was found in the range between 0.008 and 0.22 1/min due to the influence of temperature and variation of thickness of the sample.

Table 3. Coefficients for Newton equation and effective moisture diffusivity

Type of seaweeds	Drying temp., ºC	Drying coefficient, 1/min			
		1 layer	2 layers	3 layers	
Raw seaweeds	10.0	0.07(0.01)	0.015(0.01)	0.016(0.001)	
	25.0	0.13 (0.01)	0.033(0.01)	0.021(0.001)	
	38.0	0.22 (0.01)	0.055(0.01)	0.036(0.001	
Blanched	10.0	0.035 (0.001)	0.017(0.002)	0.008(0.002)	
	25.0	0.051 (0.001)	0.025(0.003)	0.013(0.002)	
	38.0	0.060 (0.001)	0.031(0.004)	0.015(0.001)	
		Effective diffusivity, D $m^2/s*10^{10}$			**Average**
		1 layer	**2 layers**	**3 layers**	
Raw seaweeds	10.0	1.50	1.20	1.50	**1.4 (0.17)**
	25.0	2.80	2.60	2.60	**2.7 (0.11)**
	38.0	4.50	4.00	5.00	**4.50 (0.5)**
Blanched seaweeds	10.0	0.95	0.90	0.90	**0.91 (0.03)**
	25.0	1.10	1.50	1.10	**1.2 (0.23)**
	38.0	2.50	2.60	2.60	**2.56 (0.05)**

The average values of effective moisture diffusivity (Table 3) increased with increasing of the drying temperature and reached the highest value of $3.5*10^{-10}$ m^2/s at 38.0 °C. The effective moisture diffusivities of blanched seaweeds were relatively lower, when compared with raw seaweeds. The results of this study were in agreement with the resent study on Saccharina latissima [11], when the effective moisture diffusivity was determined at $2.95*10^{-10}$ m^2/s at 40.0 ºC and 25.0% RH.

4. Conclusions

Drying kinetics of Saccharina latissima (raw and blanched) at low temperatures (10.0, 25.0 and 38.0 °C) was studied. The effective moisture diffusivity coefficient varied due to temperature alterations in the range between 1.4 and 4.5 10^{-10} m^2/s for raw and 0.91 and 2.56 10^{-10} m^2/s for blanched seaweeds. Significant changes in structural properties and chemical composition resulted in a much longer drying time of blanched seaweeds, when compared with raw. Drying temperature of 38.0 °C resulted in more brown color, when compared with other samples. Sorption characteristics of dried raw seaweeds depended on salt content and showed high accumulation of moisture at relative humidity of air of 80.0 %. The blanched seaweeds showed linear accumulation of moisture within increasing of relative humidity of drying air from 20.0 to 80.0 %, but high level of hysteresis was determined between sorption and desorption isotherms. The shrinkage development within dewatering of blanched and raw samples was also studied.

5. Asknowledgement

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