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Spherical Granule Production from Micronized Saltwort (*Salicornia herbacea*) Powder as Salt Substitute

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ABSTRACT: The whole saltwort plant (*Salicornia herbacea*) was micronized to develop the table salt substitute. The micronized powder was mixed with distilled water and made into a spherical granule by using the fluid-bed coater (SGMPDW). The SGMPDW had superior flowability to powder; however, it had low dispersibility. To increase the dispersibility of SGMPDW, the micronized powder was mixed with the solution, which contained various soluble solid contents of saltwort aqueous extract (SAE), and made into a spherical granule (SGMPSAE). The SGMPSAE prepared with the higher percentages of solid content of SAE showed improved dispersibility in water and an increase in salty taste. The SGMPSAE prepared with 10% SAE was shown to possess the best physicochemical properties and its relative saltiness compared to NaCl (0.39). In conclusion, SGMPSAEs can be used as a table salt substitute and a functional food material with enhanced absorptivity and convenience.

Keywords: spherical granule, saltwort, micronized powder, table salt substitute, flowability

INTRODUCTION

Saltwort (*Saliconia herbacea*) is a bioactive, annual plant that grows in high-salt coastal marshes. The saltwort plant is green from spring through summer and turns scarlet red in autumn. In a recent study, saltwort has been shown to provide beneficial biological and physiological effects as an antidiabetic and an antioxidant as well as having hypocholesterolemic and anti-aging effects (1). This plant contains large quantities of minerals such as Mg (1.9 mg/g), Ca (1.1 mg/g), Fe (0.2 mg/g), K (5.6 mg/g), and Na (10 mg/g) (2). Also, saltwort has a strong salty taste (3). Therefore, an attempt was made to spherically granulize the whole plant of micronized saltwort to use it as a table salt substitute.

Examples of beneficial effects of these whole plant sources include maintaining normal gastrointestinal function (4) and a healthy cardiovascular system (5), lowering postprandial serum glucose levels (6), and producing hypolipidemic (7) and hypocholesterolemic effects (8). In recent years, efforts have been made to process functional foods and traditional medical herbs from whole plant sources into micro-powders.

Using the whole plant could reduce waste and obtain the beneficial effects compared to plant extracts. Micronization can also reduce waste and enable whole plants to be used as food additives in the preparation of various health foods. Therefore, the application of micronization of whole plant sources has gained much attention and has led to new applications in the food industry (9,10).

However, the micronized powders of whole plant sources often are inconvenient to handle and have low product flowability, creating a need to improve these characteristics. The products obtained from a fluid-bed coater have excellent preservation characteristics, controlled release, flowability and are convenient to handle (11).

To develop the saltwort table salt substitute, the whole saltwort plant was micronized by using a pulverizer. The micronized powder was mixed with distilled water and made into spherical granules by using the fluid-bed coater (SGMPDW). To increase the dispersibility of SGMPDW, the micronized powder was mixed with the solution, containing various soluble solid contents of saltwort aqueous extract (SAE), and was made into spherical granules (SGMPSAE). Then, the physicochemical properties, sensory characteristics and relative saltiness of the SGMPSAEs were evaluated.

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MATERIALS AND METHODS

Materials

Saltwort was purchased from Jeung-Island (Jeonnam, Korea). The dried saltwort stalk was pulverized into particles with diameters less than 150 μm using an impact mill (Korean Pulverizing Machine Co. Ltd., Incheon, Korea). Four different samples of particles, which have 100, 47, 27, and 15 μm average particle sizes, were collected at different time points during the pulverization process.

Physicochemical properties of saltwort powders with various particle sizes

***Water holding capacity (WHC)*:** The WHC of saltwort powder was analyzed according to the method of Zhang et al. (12). A centrifuge tube (M) was weighed and 0.5 g of the saltwort-powder (M_1) and 7 mL distilled water were added, mixed, and settled for 30 min at 60°C. The mixture was then centrifuged for 15 min at 4,000 rpm, and the supernatant was discarded. The wetted powder in the centrifuge tube (M_2) was weighed. The WHC of the saltwort powder was calculated using the following equation:

$$\text{WHC (g/g)} = \{M_2 - (M_1 + M)\}/M_1$$

***Flowability of saltwort powder*:** The angle of repose (°) was used to characterize the flowability of the saltwort powder (13). The saltwort powder was poured slowly through a glass funnel, with an inlet diameter of 15 cm and an outlet diameter of 12 mm, to form a conical heap on a ceramic tile. The diameter (R) and height of the cone (H) were measured and the angle of the cone was calculated using the following equation:

$$\text{Angle of repose (°)} = \arctan (H/R)$$

Preparation of spherical granules with various micronized powder particle sizes (SGMPs)

***Preparation of suspension of saltwort powder and water*:** To prepare spherical granules of micronized saltwort powder, a mixture of 15% (w/v) micronized saltwort powder in distilled water was prepared and homogenized for preparation of a suspension.

***Preparation of core particle*:** Before the preparation of spherical granules, the core particles were prepared by using the fluid-bed coater (GRE-Lab 1, GRE engineering, Gyeonggi, Korea). The micronized saltwort powder suspension was constantly stirred during the fluid-bed drying process to maintain homogeneity in the double kettle at 50°C. The suspension was pumped at a flow rate of 30±5 mL/h into the fluid-bed coater. The air pressure was 200±20 kPa, and the inlet and outlet air temperatures were 110±5°C and 80 ±5°C, respectively. During the drying and coating process, the particle size can be obtained through a sample picking phase. When the particle size was found to be about 0.15 mm, the fluid-bed drying operation was stopped and the particles were collected. The particles were sieved to collect a size range between 0.10 and 0.15 mm. The collected spherical shaped particles were used as core particles for preparation of spherical granules.

***Preparation of SGMPDW with various particle sizes*:** The core particles were loaded into the fluid-bed coater. During the fluidization process, the saltwort powder suspension was sprayed continuously under the same operating conditions used for preparation of the core particles. Therefore, the saltwort powder suspension was coated around the core particle continuously, thereby enlarging the core particle. The processing status was confirmed through the sample picking phase. When the spherical granule size approached about 0.6 mm, the fluid-bed coater was stopped and the SGMPDWs were collected and sieved.

Preparation of spherical granules of micronized saltwort powder with various saltwort aqueous extracts (SGMPSAEs)

For preparation of SGMPSAEs, a mixture suspension of 15% (w/v) 47-μm (average) micronized saltwort powder in solution containing 5%, 10%, and 15% soluble solid content of saltwort aqueous extracts, respectively, were prepared and homogenized for preparation of a suspension.

The methods used for preparation of the core particles and spherical granules were the same as the methods employed for preparation of SGMPDWs. After successful preparation of the spherical granules using a fluid-bed coater, the physical changes must be confirmed for applications in the food industry. Therefore, comparisons of the physical and sensory characteristics were performed.

Comparison of the physicochemical and sensory properties of SGMPSAEs

***Size distribution and yield*:** On the basis of the weight of the collected spherical granules of each sieve, the diameter of the spherical granules was measured using a sieve analysis (14). The spherical granules between 0.2 and 0.6 mm were defined as the final product. The distributions of the diameters of the spherical granules were divided into groups of less than 0.2 mm diameter, between 0.2 and 0.6 mm diameter, and larger than 0.6 mm diameter. The dry weight of the spherical granules between 0.2 and 0.6 mm diameter was used to calculate the yield according to the following equation:

Yield (%) = (Dry weight of spherical granule between 0.2 and 0.6 mm diameter/ Total input dry weight of saltwort suspension) × 100

***Dispersibility*:** The dispersibility was measured using a modification of the procedure of Wright et al. (15). One

Table 1. Descriptors and references for sensory descriptive analysis of micronized saltwort powder spherical granules

Sensory attribute	Descriptors	Definition of descriptors	Reference	Reference point[1)]
Appearance	Regularity	Regular properties related to particle shape	Glass bead	10
	Moisture	Wet appearance related to wet mud surface	Wet mud surface	12
	Greenish	Color related to green	Munssel system YG5	7
Texture	Strength	Strength of the granule with respect to breakage or deformation	Frozen coffee granule	5

[1)]Reference point means the strength of reference.

gram (dry weight) of each sample was added to 50 mL distilled water at 80°C in a 250-mL Erlenmeyer flask and shaken vertically on a shaker (SK 300 model, Jeio Tech., Gyeonggi, Korea). The time required for complete dispersal into the water was determined in triplicate for each sample.

***Flowability*:** The angle of repose (°) was used to characterize the flowability of SGMPSAEs (13). The methods used and the representations of results are the same as those used to determine and express the flowability of the saltwort powder, except that the spherical granules of saltwort powder were prepared and measured.

***Sensory properties*:** Nine panelists (5 women and 4 men; ages ranging from 22 to 30 years) were selected to evaluate the sensory characteristics of the spherical granules of saltwort powder. Attributed descriptors were developed by panelists using the quantitative descriptive analysis (QDA) (16). The descriptors and references are listed in Table 1. The training was performed using saltwort powder and its granules. The reference control was served along with the saltwort powder and its granules during training. Also, the panelists were asked to quantify the difference compared to the reference in descriptive terms on a scale of 0 to 15. The training was performed through 4 sessions and each session took one hour. For the sample presentation for descriptive analysis, 1 g of each sample was placed on a white plate 15 cm in diameter and labeled with a blinded three-digit code. These samples were presented to panel members seated in individual booths. Panelists evaluated the taste sensory characteristics of the SGMPSAEs on the 15 cm line scale with descriptors ranging from "not detectable" to "intense". The results were statistically analyzed.

***Relative saltiness*:** The paired comparison method (17) was used to compare six concentrations of NaCl, which were 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6 %, with solutions of 1% SGMPSAEs at room temperature. Panelists compared two pairs during each 10 min evaluation period. The 9 trained panel members who attended the sensory descriptive analysis also evaluated the relative saltiness. Within all test series, samples of approximately 20 mL of solution were served in a random order in 50-mL beakers. The percentage of the participants who perceived NaCl as saltier than solutions of 1% SGMPSAEs was recorded. The relative saltiness of SGMPSAEs was calculated using the proportional method (17).

Table 2. Water holding capacity and angle of repose (°) of saltwort powder with various particle sizes

Particle size of saltwort powder (μm)	Water holding capacity (g/g powder)	Repose angle (°)
15	3.56±0.04[1)a2)]	41±0.3[a]
27	3.05±0.03[ab]	40±0.8[ab]
47	3.04±0.07[b]	39±0.5[b]
100	2.81±0.17[c]	37±0.4[c]

[1)]Mean±SD (n=4).
[2)]Mean values with the same letter in the same column are not significantly different.

Statistical analysis

The data are presented as mean±standard deviation (SD) in triplicate except for the sensory evaluation, which was performed once. Statistical evaluation of the results was performed by analysis of variance (ANOVA) followed by Duncan's multiple comparison. Statistical significance was defined as $p<0.05$. The data were analyzed using the Minitab 13 statistical software package (Minitab Inc., State College, PA, USA).

RESULTS AND DISCUSSION

Physicochemical properties of saltwort powders with various particle sizes

***Water holding capacity*:** One of the benefits of whole saltwort powder as a functional food material is its high content of dietary fiber (2,18). Dietary fiber plays an important role in suppressing diseases (19-21). The water binding capacity of dietary fiber is generally related to its structure, density, and the quantity and nature of its water binding sites (22-24). The water holding capacity of saltwort powder with various particle sizes is shown in Table 2. In our study, the smaller particle sizes had a higher capacity for water holding. These results are similar to those previously reported by Chau et al. (7). Also noted was the high water binding, holding and swelling capacity of the micronized fibers could be potentially used as low calorie bulk ingredients in foods, which require moisture retention.

Flowability: The flowability of the micronized powder is represented as the angle of repose (°) (12). The values determined for the angle of repose (°) are shown in Table 2. The smaller particle sizes of saltwort powder have the higher angle of repose (°). Particle size has been considered as one of the most important physical properties affecting the flowability of particles (25). An inverse relationship exists among the angle of repose and the mean particle size (26). Because the powders with lower values for the angle of repose (°) have higher flowability (27), the smaller particles have decreased flowability. The micronized powder makes the material useful as a low calorie bulk ingredient with the advantage of providing dietary benefits. However, the flowability of powders tends to cause problems in food applications, and granules are more desirable due to improved flowability.

Physicochemical and sensory properties of SGMPDWs

Size distribution and yield: The size distributions and yields obtained from each of the micronized saltwort powders are shown in Table 3. The appearance of the spherical granule is shown in Fig. 1. The spherical granules with diameters less than 0.20 mm appeared powder-like (Fig. 1A). The spherical granules with diameters over 0.60 mm were agglomerated spherical granules (Fig. 1C). To reduce the agglomeration, the moisture within the particles must be removed as soon as possible. In this study, the small granules with diameters under 0.2 mm were more likely to be obtained from the smaller powder particles. This result is similar to the results of Scott et al. (28), who reported that because smaller powder particles produce stronger granules, preferential growth of small particles might occur and give rise to increased amounts of small particles. More highly aggregated spherical granules were obtained from larger particle sizes than from smaller particle sizes. We assumed that particle sizes over 100 μm were the most aggregated because they have poor flow characteristics in the fluid-bed coater.

Dispersibility: Dispersibility is defined as the ability of the powder mass to break up into primary particles in a liquid (29). A powder with high dispersibility takes less time and mixing effort to disperse into solution than a powder with low dispersibility. The dispersibility was found to be inversely related to the dispersal time reported (Table 3). Thus, a powder with a short dispersal time was considered to be highly dispersible. In this study, the spherical granules made with higher particle sizes had higher dispersibility. We assumed that the powder with smaller particle sizes has low dispersibility because it generally has a low total surface area and few water binding sites.

Flowability: The flowability was analyzed by measuring the angle of repose (Table 3). In this study, the flowability of spherical granules prepared with various powder particle sizes did not exhibit differences among samples. However, the angles of repose of spherical granules were much lower than those of the powders,

Table 3. Size distribution, yields, dispersibility, and angle of repose (°) of spherical granules obtained from various saltwort powder particle sizes

Particle size of saltwort (μm)	Size distribution (%)			Yields of granules (%)	Total dispersion time (sec)	Repose angle (°)
	Below 0.2 mm	0.2~0.6 mm	Over 0.6 mm			
15	12.73	81.12	6.15	80.27	112.6±4.2[1)a2)]	18±1.8[a]
27	11.63	78.35	10.02	77.29	103.3±2.3[b]	17±0.8[a]
47	9.51	79.60	10.89	78.84	93.6±2.2[c]	17±1.2[a]
100	8.24	70.97	20.79	68.95	73.2±2.0[d]	17±1.3[a]

[1)]Mean±SD (n=4). [2)]Mean values with the same letter in the same column are not significantly different.

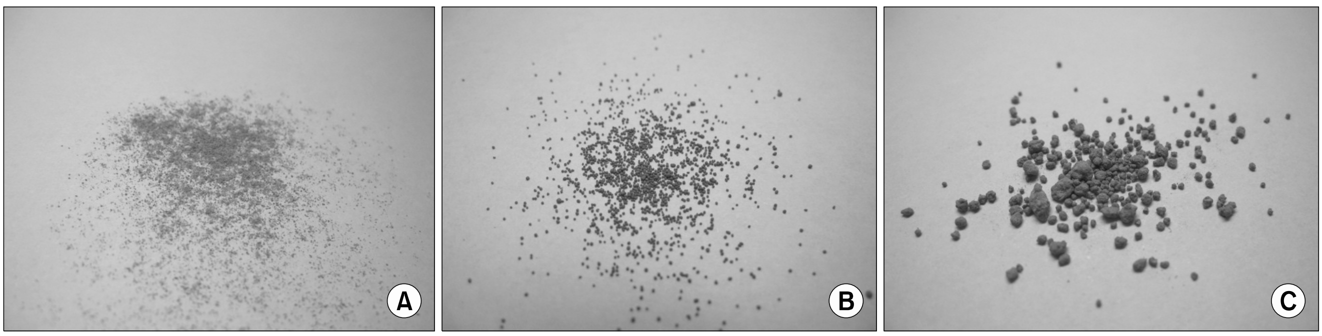

Fig. 1. Images showing the measured particle sizes of saltwort powder granules obtained with the fluidized bed coater. (A) Less than 0.2 mm, (B) 0.2~0.6 mm, (C) larger than 0.6 mm.

Table 4. Results of sensory descriptive analysis for spherical granules made with various saltwort powder particle sizes

Sensory attribute	Descriptors	Saltwort powder particle size (μm)			
		15	27	47	100
Appearance	Regularity	8.89±2.37[1)a2)]	8.22±2.11[a]	7.20±3.55[ab]	5.11±2.62[b]
	Moisture	7.67±2.83[b]	8.00±2.40[b]	9.20±3.52[a]	9.89±2.42[a]
	Color	8.44±3.50[b]	8.56±1.88[b]	9.10±2.42[ab]	10.00±2.74[a]
Texture	Strength	7.89±2.98[a]	7.89±2.06[a]	6.30±2.10[ab]	5.44±2.35[b]

[1)]Mean±SD (n=9).
[2)]Mean values with the same letter in the same row are not significantly different.

indicating that the spherical granulation significantly increased the powder flowability.

***Sensory properties*:** The appearance and texture of each sample was subjected to sensory evaluation and the results are shown in Table 4. The color and moisture of the samples with larger particle sizes were greenish and moist. However, the spherical granules prepared from larger powder particle sizes had less regularity and granule strength. This result is similar to findings by Keningley et al. (30) and Johansen and Schæfer (31). These investigations concluded that low viscosity produces sufficiently strong granules when the particle size is small, while higher viscosity is necessary to obtain sufficient strength to avoid breakage of larger particles. The samples made with smaller particle size showed a more regular appearance and stronger texture. These results were similar to a previous finding whereby the presence of smaller particles in granulation could result in denser, less porous products (32) due to the stronger texture.

***Selection of particle size for further analysis*:** When the spherical granules were prepared with various powder particle sizes and water, the spherical granules had low dispersibility. In addition, the average particle size of 100 μm was not amenable for production of spherical granules because it produced a high extent of agglomeration and low granule strength, although reducing the particle size creates cost benefits. The smallest particle size averaged 15 μm and was the most adjustable for production of spherical granules; however, the micronization process would be costly. The powder particle size average of 47 μm did not have a significantly different appearance and strength relative to the 15 and 27 μm particles, and would be less costly to produce than the smaller. The smaller powder particle needs more pulverizing time. Therefore, the 47-μm particle was selected for further study.

Physicochemical properties of SGMPSAEs

***Size distribution and yield*:** The size distributions and yields obtained from each micronized particle of saltwort powder and saltwort aqueous extract are shown in Table 5. In this study, the size distribution and yields among spherical granules made with 47-μm average particle size powder and various saltwort extracts did not significantly differ according to the percentage of solid content of the aqueous solution used.

***Dispersibility*:** The dispersibilty of the spherical granules made with the 47-μm average particle size powder and various saltwort extracts had statistical differences among samples (Table 5). The addition of saltwort aqueous extracts can improve the dispersibility. The soluble solid content of saltwort aqueous extracts increases with less time being needed for dispersion. In this case, the aqueous extract wets and spreads throughout the interstices between powder particles and the soluble solid of the aqueous extract forms bridges that hold the particles together by capillary and viscous forces (33). The soluble solid bridge can function as a channel for water adsorption. Dispersion is promoted by a high binding viscosity, which enables an increase in the intergranular particle size (34). Therefore, we assumed that the soluble solid in the spherical granules of saltwort powder may play a

Table 5. Size distribution, yields, dispersibility, angle of repose (°) and relative saltiness of saltwort powder spherical granules made with various soluble solid contents of saltwort extract

Soluble solid content of saltwort extract (%)	Size distribution (%)			Yields of granules (%)	Total dispersion time (sec)	Repose angle (°)	Relative saltiness[3)]
	Below 0.2 mm	0.2~0.6 mm	Over 0.6 mm				
0	9.51	79.60	10.89	78.84	93.6±2.2[1)c2)]	17±1.2[a]	0.30
5	9.12	80.85	10.03	79.29	26.3±1.9[b]	16±0.9[a]	0.35
10	8.93	81.95	9.12	81.54	16.4±1.8[c]	17±0.8[a]	0.39
15	8.97	81.25	9.78	80.77	13.5±1.3[d]	18±1.3[a]	0.42

[1)]Mean±SD (n=4).
[2)]Mean values with the same letter in the same column are not significantly different.
[3)]Relative saltiness was compared to NaCl and calculated by the Amerine et al. method (17).

role as a water adsorption channel.

***Flowability*:** The flowability analysis was performed by measuring the angle of repose (°) of spherical granules with the 47-μm average particle size and various saltwort extracts (Table 5). The flowability among the spherical granules did not have any significant differences.

***Relative saltiness*:** Relative saltiness of SPMGSAE solutions was shown in Table 5. In this study, the more SAE increased, the saltier the taste. Salt is a vital nutrient and is necessary for the body to function, but the Consensus Action on Salt and Health (CASH) considers the average daily salt consumption in the western world, between 10 and 12 g, far too high. Numerous scientists (35) are convinced that high salt intake is responsible for hypertension, a major risk factor for cardiovascular disease. Therefore, the reducing of salt intake is a suggestive idea for decreasing the risk for cardiovascular related diseases. As the results suggest, since SPMGSAE has a salty taste as well, SPMGSAE can be used as an alternative to salt and a functional food material with enhanced absorptivity and convenience.

CONCLUSION

Whole plants were micronized for altering the surface area and functional properties of tested samples to develop materials with improved characteristics for food development and other applications in biological or material sciences. Naturally, saltwort has a salty taste and contains various minerals. In making a table salt substitute, dried saltwort whole plant was micronized; however, because of poor flowability characteristics, the micronized plant powders are difficult to use in food preparations. To increase the flowability of micronized powder, the powders were granulated, using a fluid-bed coater, which markedly improved flowability. When the plant aqueous extract was used to prepare the preparation of spherical granules, the dispersibility was also improved. Also, the spherical granule of micronized saltwort powder was evaluated to have a relative saltiness of 0.39 compared with NaCl. Therefore, spherical granules of micronized saltwort plant powders and plant aqueous extracts using a fluid-bed coating process may lead to additional applications of such powders in the food processing industry.

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