

Influence of Heat Treatment on the Physicochemical Property and Mineral Composition of Various Processed Salts

Sung-Hee Han¹, Seog-Won Lee², and Chul Rhee*

Division of Food Bioscience and Technology, College of Life Sciences and Biotechnology, Korea University, Seoul 136-701, Korea

¹Institute of Life Science and Natural Resources, Korea University, Seoul 136-701, Korea

²Department of Food and Nutrition, Yuhan College, Bucheon, Gyeonggi 422-749, Korea

Abstract The effects of heat treatment on the physicochemical properties and mineral composition of sun-dried salt were investigated. The salts parched at high temperature were appeared the higher alkalinity and the lower oxidation-reduction potential (ORP) than the samples without heat treatment. The commercial salts (bamboo salt and yellow loess salt) and the sun-dried salt parched at high temperature had relatively higher sodium ion content (418-450 ppm) compared to that (418.0 ppm) of refined salt. The increase of calcium ion occurred in the salts parched at high temperature compared to the sun-dried salt without heat treatment, but the magnesium ion was vice versa. The commercial salt, yellow loess salt had highest turbidity (0.973) whereas sun-dried salt showed lowest level (0.097) among the tested samples. Turbidity of heat treatment samples decreased as solubility increased. The maximum concentration of dialyzed salt was reached after 4 hr regardless of various processed salts, but those had no difference significantly among the tested samples. The X-ray diffraction patterns of the parched sun-dried salts showed different peak intensity with common salts, and they were similar to the patterns of oxide salts, especially MgO. The maximum value (2.56%) of MgO appeared in the sun-dried salt parched at 1,400°C.

Keywords: parched salt, physicochemical property, mineral, oxide salt

Introduction

Salt is one of the essential nutrients in human body and also has been used to improve the flavor, preservation, and processed suitability of food. In general, salt denotes a single substance, sodium chloride (NaCl). It fulfills several indispensable body functions such as transmission of molecules and nerve impulses, digestion of food, maintenance of osmosis and body heat, and muscular action (1,2). On the other hand, salt is a flavor enhancer, helping to reduce bitterness and acidity, and bringing out other flavors in the food. It also has a number of technological uses in foods such as improving the binding of proteins in meat and fish products (3-5). However, salt is known and accepted that excessive salt consumption leads to hypertension or is not good for health. Several researchers have demonstrated a relationship between salt intake and hypertension (6-8).

Salt can divide into rock salt and sea salt. The sea salt prepared by concentration of sea water was main edible salt, but the consumption of rock salt increases because of environmental pollution (9). The function of salt depends on almost NaCl, but it also contains traces of other minerals (10). Among the various salts, the sun-dried salt is general salt. sun-dried salt which has been obtained from sea water by evaporation in shallow pits or basins, by the heat of sun. So sun-dried salt has sufficient various minerals and sodium whereas it had low NaCl than other refined salt. Though we need some salt in our diet, most people consume much more than necessary. There are

necessary to research for the fortification of salts processed using sea salt and rock salt. The reduction of NaCl intake and the fortification of salt have been mainly reported for the addition of specific mineral compounds such as iodine and iron (11,12) and soluble seaweed minerals (2,13). These processed salts have various functions by minerals contained, but the reducing levels of NaCl in composition of salt may also result in an alteration of flavor profile in food.

Most processed salts have prepared by the addition of various minerals and heat treatment below melting point of NaCl (about 800°C). In Korea, the processed salts divide into different kinds according to heat treatment methods (14). At present bamboo salt and yellow loess salt is being manufactured by heat treatment at high temperature above melting temperature of NaCl. Their physicochemical properties depend on various processed conditions such as heating temperature, heating time, parching times, and material of parching container. This processed method is a very specialty and has originality (15,16). However more research for safety, physiological function, and processed suitability of these salts is necessary. Also the physicochemical properties for sun-dried salt itself after heat treatment at high temperature above melting point of NaCl is not reported.

Therefore, the purpose of this research was to investigate the influence of heat treatment at high temperatures on physicochemical properties of sun-dried salt itself.

Materials and Methods

Materials and heat treatment of sun-dried salt Refined salt and sun-dried salt (Daesang Co., Seoul, Korea), bamboo salt (Yungjin Green Good Co., Hanam, Korea),

*Corresponding author: Tel: +82-2-3290-3020; Fax: +82-2-928-1351

E-mail: rhee2@korea.ac.kr

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and yellow loess salt (Biosalt Co., Hongseong, Korea) were purchased in local market. Twenty g of sun-dried salt were weighed and put it into the crucibles. Then, the samples were treatment by heating for 10 min at different temperatures (300, 800, and 1,400°C). After then, parched sun-dried salts were grounded by a mortar (Food Mixer FM-909T; Hanil Co., Seoul, Korea) and passed through 100-mesh (150 µm) sieve.

Measurement of NaCl, moisture, water activity, pH, and oxidation-reduction potential (ORP) All samples were analyzed for NaCl content according to the Mohr methods (17) and for moisture content according to the AOAC methods (18). Water activity of samples was measured using thermoconstranter (Novasina, Zurich-Talstrasse, Switzerland) at 20°C. The pH and ORP of salt solutions (1%, w/v) were analyzed using pH meter (MO 220; Mettler Tole Do, Columbus, OH, USA) and ORP meter (Hanna Instruments, Seoul, Korea).

Analysis of mineral composition of various salts To analyze the mineral composition of various salts, 0.1 g of salt was dissolved in deionized water and then was diluted to 10 ppm. The salt solution was filtered through 0.45-µm filter (PTFE syringe filter No. 6784 2504, Whatman International Ltd., Maidstone, UK) and then analyzed by inductively coupled plasma atomic emission spectrophotometer (ICP-AES) (Jobin Yvon 138 Ultima 2C, Source: Argon plasma (6000K), Horiba Jobin Yvon Inc., Edison, NJ, USA). Instrumental parameters for the determination are follows: forward power 1,000 W, plasma flow 12 L/min, auxiliary flow 0 L/min, nebulizer pressure 2.88 kPa, and replicate read time 0.5 sec. Also, sample induction settings are follows: pump rate 20 rpm, rinse time 40 sec, and cyclonic spray chamber.

Solubility and turbidity One-hundred mg of salt samples were dissolved in 10 mL of deionized water, and then the salt solutions were mixed for overnight in water bath at 25°C and 200 rpm. After dissolving, the solutions were passed through the filter paper (Whatman No. 3, Whatman International Ltd.) preweighed. The filter papers were dried in dry oven at 80°C and was reweighed. The solubility was calculated from the residue content in the filter paper to the salt content in the filtrate.

Turbidity of salt solutions (1%, w/v) was analyzed by spectrophotometer (Spectronic 20D+, Spectronic Instrument, Rochester, NY, USA) at A_{650} . The optical density (OD) values from the spectrophotometer were converted to turbidity (T) values by the relationship ($T = 2.303 \times OD/L$) where L is the path length (19).

In vitro sodium transport *In vitro* sodium transport were investigated by dialysis (D7884: cut-off Mw <1,200, Sigma-Aldrich, St. Louis, MO, USA.) using a glucose transport model (20). Two-hundred mg of salt samples in 6 mL of 0.1% sodium azide were added to dialysis tube. Then, the tube was put into a 150-mL capped cylindrical containing 100 mL of 0.1% sodium azide and shaken at 75 rpm in a water bath at 25°C for 18 hr. As a control, only 0.1% sodium azide solution was added to dialysis tube. Aliquots of 1 mL dialysate were removed at regular inter-

vals and the salt concentration was measured using a salt meter (TM-30D; Takemura Electric Works Ltd., Tokyo, Japan).

X-ray diffraction X-ray diffraction (XRD) patterns of the various processed salts and the oxide salts (CaO, MgO, and Na_2O_2) were obtained by using a high resolution X-ray diffractometer (D8 Discover; Bruker, Karlsruhe, Germany) at room temperature with CuK_{α} radiation (λ , 0.3154 nm). The X-ray powder diffraction patterns were recorded in the angular range of 5-100° with a step size of 0.03°. The scan rate was 20 sec/step.

Determination of MgO Various salts was dried at 800°C and cooled in a desiccator for 30 min. The dried salts weighed accurately about 0.5 g and transferred to the crucible. Five mL of deionized water, 10 mL of conc. HCl and 10 mL of perchloric acid ($HClO_4$) was added to the crucible. And then the covered crucible was gradually heated. After thick white fumes were evolved, it was heated for another 10 min. After cooling, 50 mL of deionized water of 40°C and 5 mL of diluted HCl (1→2) was added and heated slightly. The solution was immediately passed through the filter paper (Whatman No. 4) and then added water to the filtrate to make exactly 500 mL (A solution). The mixing solution (10 mL of A solution + 90 mL of deionized water + 5 mL of ammonia · ammonia chloride buffer (pH 10.0) + 2 drops of eriochrome black T) was immediately titrated with 0.01 M ethylenediamine tetraacetic acid (EDTA) until the red color of solution changes to blue (B mL) (21). The MgO was calculated as

$MgO (\%) = (A - 0.2B) \times 2.0152 / \text{weight of the sample (g)}$

Statistical analysis Analysis of variance (ANOVA) was performed, and the difference among samples were determined by Duncan's multiple range test using the Statistical Analysis System.

Results and Discussion

Quality characteristics of various processed salts The quality characteristics of various processed salts are shown in Table 1. The refined salt had significantly high NaCl content (about 94%) compared to those (80-85%) of other salts. This result is similar to other report (10), and it seems to be caused by the minerals contained in sun-dried salt. Also the content of NaCl contained in parched salts is known to be affected by the processed conditions such as heating temperature, heating time, and the number of parching times (16). The moisture content of refined salt and parched salts had lower values (range of 0.8-1.5%) than that (about 7.6%) of natural sun-dried salt. The moisture content of parched sun-dried salt showed a decreasing trend as the heating temperature was increased from 300 to 1,400°C. These results indicate that the heat treatment may affect to moisture content of salt. On the other hand, water activity of sun-dried salt itself had the highest value (0.53) among tested samples, but the sun-dried salt parched at 1,400°C showed the lowest value (0.41). Overall, all parched salts (parched sun-dried salts and commercial parched salts) and refined salt revealed

Table 1. Quality characteristics of various salts

Sample	NaCl (%)	Moisture (%)	Water activity	pH	ORP ¹⁾ (mV)
Refined salt	93.91±1.18 ^{a,2)}	1.17±0.07 ^c	0.412±0.001	7.47±0.29 ^e	244.00±1.73 ^a
sun-dried salt	80.49±3.48 ^b	7.56±0.24 ^a	0.532±0.003	9.12±0.06 ^d	175.00±3.00 ^d
sun-dried salt-300 (parched at 300°C)	82.21±3.59 ^b	1.00±0.01 ^{cd}	0.424±0.058	11.15±0.04 ^a	76.67±1.15 ^g
sun-dried salt-800 (parched at 800°C)	83.34±3.05 ^b	1.02±0.00 ^{cd}	0.435±0.001	11.08±0.54 ^b	102.67±1.15 ^f
sun-dried salt-1,400 (parched at 1,400°C)	84.87±2.33 ^b	0.95±0.05 ^{de}	0.406±0.002	10.17±0.28 ^c	143.33±2.89 ^e
Bamboo salt	84.54±2.11 ^b	0.80±0.18 ^c	0.444±0.002	10.10±0.00 ^c	107.67±1.15 ^f
Yellow loess salt	81.77±5.32 ^b	1.54±0.13 ^b	0.428±0.000	10.22±0.00 ^c	105.33±2.31 ^f

¹⁾Oxidation-reduction potential.

²⁾Means±SD (n=3); ^{a-f}superscript letters in a column indicate significant difference at $p < 0.05$ by Duncan's multiple comparison.

relatively lower water activities compared to that of sun-dried salt. These results show a correlation between the improvement of food preservation and the parched salts (22,23).

In case of pH, the refined salt had near neutral pH (7.47), but the other salts showed an alkalinity in range of 9.12–11.15. Especially when the sun-dried salt was heated at high temperature, the alkalinity of parched salts showed an increasing trend. This is probably due to the increase of oxide salts after heat treatment. The ORP of refined salt had the highest value (244.00 mV) among the samples. However, ORP of the sun-dried salt and parched salts was significantly appeared low values, and the lowest ORP (76.67 mV) revealed in the sun-dried salt parched at 300°C. Each ORP of bamboo salt and yellow loess salt was 107.67 and 105.33 mV, respectively. These results indicate that the heat treatment is an important factor on the physicochemical property of sun-dried salt. In general, the salt intake having lower ORP is known to reduce the hydroperoxides occurred in human body (2,23).

Mineral composition of various salts Mineral contents of various processed salts are shown in Table 2. It shows that the heat treatment at high temperature caused the change of mineral composition. The main mineral was sodium ion in all salt samples. The commercial salts and sun-dried salt parched at high temperature had relatively higher sodium ion content compared to that (418.0 ppm) of refined salt. The heat treatment on the sun-dried salt caused a great increment in calcium content as the heat temperature was increased from 300 to 1,400°C. This can be attributed to the difference of bond energy among salts including calcium and sodium ions. The total molecular bond energy of salt including calcium ion has lower than did sodium ion. Therefore, if the temperature of salt with calcium ion

increased, it could be easily separated than salts with sodium ion (25). In case of the commercial salts parched with bamboo and loess, the increment of calcium ion was lower than those of sun-dried salt itself. The content of magnesium ion in the sun-dried salt and the parched salts appeared high values compared to that of refined salt, but its content showed a decreasing trend as the heating temperature was increased. Overall changes of mineral composition when the salts were heated were confirmed with XRD analysis (Fig. 4); these trend is similar to those of other reports. sun-dried salt had high major mineral content than refined salts that may be results in different of material itself. However, when the same sun-dried samples were treatment in high temperature, the mineral composition was changed. Kim and Ryu (16) reported when the same bamboo samples were heated different temperature, the content of mineral had affect to the heating temperature and times. And as the magnesium ion content of major element in bamboo salt decreased as heating temperature increased. However, as minor elements like as copper ion and manganese decreased as heating temperature increased (14,15).

Solubility and turbidity Solubility of various processed salts at concentration of 1% and 25°C was shown in Fig. 1. All salt samples had high levels (about 96%) of solubility. However, overall, the heat treatment for the salt caused a reduction of solubility. The refined salt showed the highest solubility value (99.9%) and the bamboo salt had the lowest solubility value (95.6%) among the samples. The relatively low solubility of the parched salts can be attributed to the generation of oxide salts when the salts were heated at high temperature above melting point of NaCl. Also this low solubility can cause a haze in salt solution, but this phenomenon disappears by a little addition of organic acids.

Table 2. Mineral composition of various salts (ppm)

Sample	Ca	Cu	Fe	K	Mg	Mn	Na	S
Refined salt	0.500	0.005	0.005	15.42	4.630	0.005	417.6	6.886
sun-dried salt	0.258	0.005	0.005	2.463	8.643	0.005	404.3	5.861
sun-dried salt-300 (parched at 300°C)	0.280	0.005	0.005	2.453	7.039	0.005	424.6	5.188
sun-dried salt-800 (parched at 800°C)	0.610	0.005	0.005	2.673	5.591	0.005	450.6	7.075
sun-dried salt-1,400 (parched at 1,400°C)	0.634	0.005	0.005	2.703	4.606	0.006	442.5	6.886
Bamboo salt	0.280	0.005	0.005	3.506	6.204	0.005	439.5	9.766
Yellow loess salt	0.270	0.005	0.005	2.259	5.400	0.005	418.3	5.673

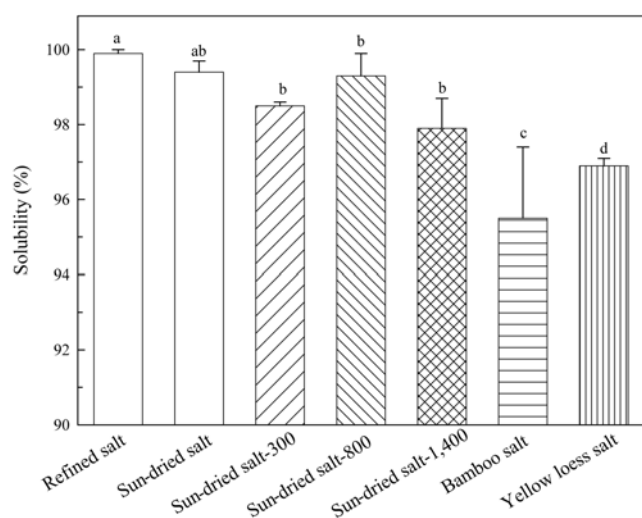


Fig. 1. Changes of solubility of various processed salts at concentration of 1% and 25°C. Different letters indicate significantly different among the various salt samples ($p < 0.05$).

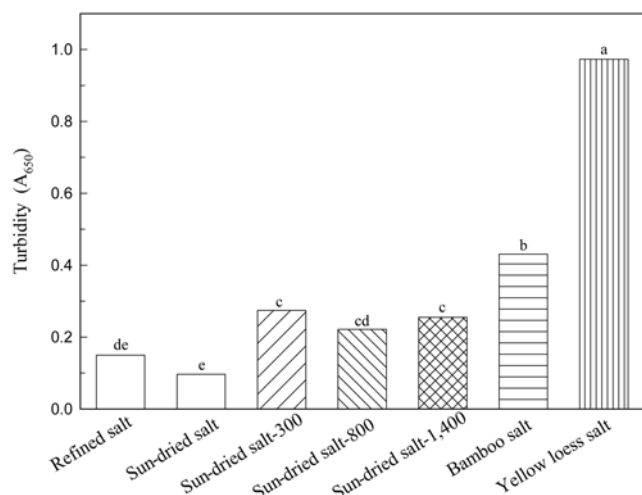


Fig. 2. Turbidity of various processed salts at concentration of 1% and 25°C. Different letters indicate significantly different among the various salt samples ($p < 0.05$).

Turbidity of all salt samples is shown in Fig. 2. Yellow loess salt had highest turbidity (0.973) whereas sun-dried salt showed lowest level (0.097) among the tested samples. Overall the heat treatment for the salt increase the turbidity, and its increment appeared higher values than decrement of solubility (Fig. 1). Also the high turbidity of bamboo salt and yellow loess salt is probably due to the inclusion of more insoluble components compared to other salt samples (15).

Influence of heat treatment on dialysate salt concentration The difference of dialysate salt concentration among the various processed salts is shown in Fig. 3. The dialysate salt concentrations were rapidly increased for 1 hr and then until 2 hr its concentration was gradually increased. The transport of sodium was reached to maximum value regardless of the kind of salts after 4 hr dialysis. The retarding effect graph for sodium transport was revealed discontinuity with dialysis time because that seems to be

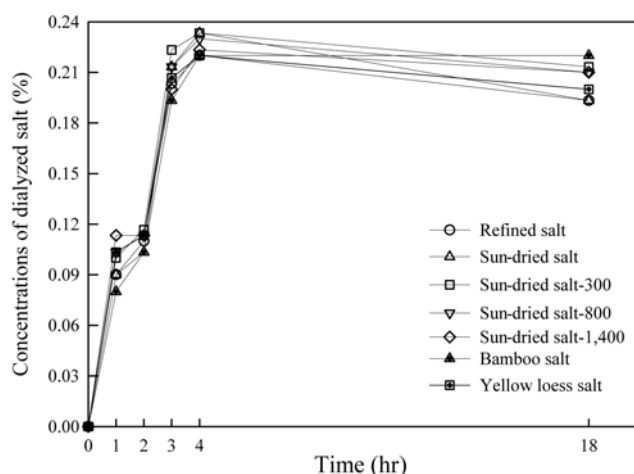


Fig. 3. Difference of dialysate salt concentration in various processed salts after dialysis for 18 hr at 25°C.

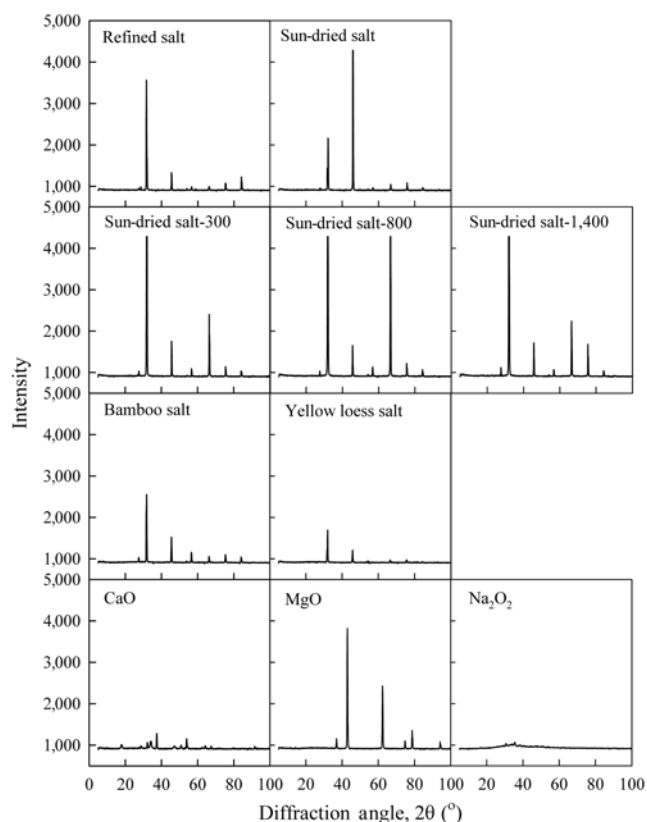


Fig. 4. X-ray diffraction patterns of the various processed salts and the oxide salts.

difference of ionic bond and molecular weight of salts (25). Overall the sodium transport phenomenon of the refined salt and parched salts was similar trend and there did not show significantly difference. These results seem to be the basis data for supporting to previously reported research (1). Accordingly, we think that the heat-treated sun-dried salt have no difference with refined salt for blood pressure.

XRD patterns of the various processed salts and oxide salts XRD patterns of all salt samples are shown in Fig.

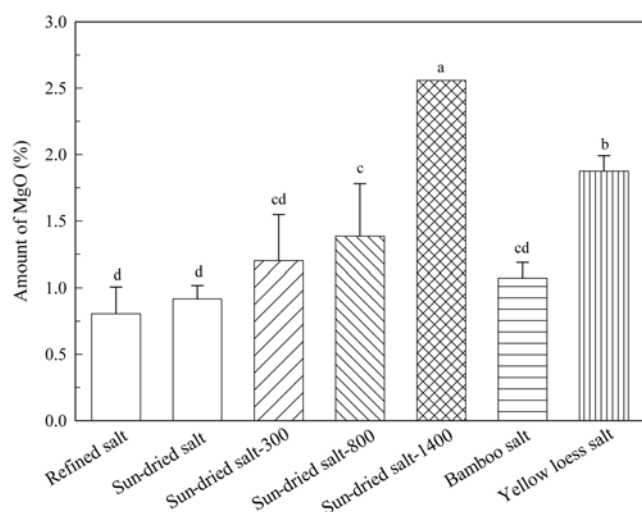


Fig. 5. Amount of MgO contained in various processed salts. Different letters indicate significantly different among the various salt samples ($p < 0.05$).

4. Also, XRD pattern of various oxide salts was revealed to confirm the production possibility of oxide salts when the sun-dried salt was heated at high temperature. The XRD patterns of refined salt were characterized by peaks at angles of 31 and 45° and this was similar to those of sun-dried salt and parched salts. However, the sun-dried salts heated at high temperature also had another peaks. Especially, the parched sun-dried salts showed high intensive peaks at angle of 66°. This indicates that the mineral compositions of salts were influenced by heat treatment. XRD pattern of CaO showed strong intensive peaks at 37 and 53°. MgO was appeared strong intensive peaks at angles of 37, 43, 63, 74, 78, and 94°. In Na_2O_2 was had strong intensive peak at angle of 38°.

We could confirm that the XRD patterns of the parched sun-dried salts were similar to the patterns of oxide salts, especially MgO. So, we suppose that the small quantities of calcium ion or magnesium ion contained in sun-dried salt were changed to oxide salts as high temperature. This result was similar to research of Kim *et al.* (15).

MgO contained in various processed salts The content of MgO contained in various processed salts is shown in Fig. 5. The content of MgO showed a increasing trend by heat treatment, and the highest value (2.56%) appeared in the sun-dried salt heated at 1,400°C. The refined salt and sun-dried salt without heat treatment had no significant difference, and they appeared to contain MgO below 1%. These result could confirmed with X-ray diffraction pattern analysis (Fig. 4).

In this study, we have confirmed that the heat treatment of sun-dried salt itself only at high temperature could cause change of physicochemical property as well as mineral composition of sun-dried salt. These mean that the parched salts used as an additive in food processing can affect the quality characteristics of product, whereas the influence on sodium transport had no difference significantly.

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References

- Bang JH, Park BY, Kim DS. Effects of bamboo salt ingestion on blood pressure and serum electrolytes. *J. Korean Soc. Hyg. Sci.* 8: 87-95 (2002)
- Kim DH, Rhim JW, Lee SB. Characteristics of seaweed salts prepared with various seaweeds. *Korean J. Food Sci. Technol.* 35: 62-66 (2003).
- Choi YJ, Lin TM, Tomlinson K, Park JW. Effect of salt concentration and temperature of storage water on the physicochemical properties of fish proteins. *Lebensm. -Wiss. Technol.* 41: 460-468 (2008)
- Niamnuy C, Devahastin S, Soponronnarit S. Changes in protein compositions and their effects on physical changes of shrimp during boiling in salt solution. *Food Chem.* 108: 165-175 (2008)
- Papastamatiou F, Gerasopoulos D, Siomos A, Bloukas JG. Effect of degree of cutting of leek on physicochemical characteristics of Greek traditional sausages. *Meat Sci.* 75: 648-654 (2007)
- Graudal N. Commentary: Possible role of salt intake in the development of essential hypertension. *Int. J. Epidemiol.* 34: 972-974 (2005)
- Haddy FJ. Role of dietary salt in hypertension. *Life Sci.* 79: 1585-1592 (2006)
- Tekol Y. Irreversible and reversible components in the genesis of hypertension by sodium chloride (salt). *Med. Hypotheses* 70: 255-259 (2008)
- Shin TS, Park CK, Lee SH, Han KH. Effects of age on chemical composition in sun-dried salts. *Korean J. Food Sci. Technol.* 37: 312-317 (2005)
- Park JW, Kim SJ, Kim SH, Kim BH, Kang SG. Determination of mineral and heavy metal contents of various salts. *Korean J. Food Sci. Technol.* 32: 1442-1445 (2000)
- Narasimha Rao BS, Vijayasathya C. Fortification of common salt with iron: Effect of chemical additives on stability and bioavailability. *Am. J. Clin. Nutr.* 28: 1395-1401 (1975)
- Harris MJ, Jooste PL, Charlton KE. The use of iodised salt in the manufacturing of processed foods in South Africa: Bread and bread premixes, margarine, and flavourants of salty snacks. *Int. J. Food Sci. Nutr.* 54: 13-19 (2003)
- Kim YM, Byun JY, NamGung B, Jo JH, Do JR, In JP. Studies on functional salts fortified with seaweed components. *Korean J. Food Sci. Technol.* 39: 152-157 (2007)
- Moon DS, Kim HJ, Shin PK, Jung DH. Characteristics of chemical contents of horizontal spray salts from deep ocean water. *J. Korean Fish. Soc.* 38: 65-69 (2005)
- Kim SH, Kang SY, Jung KK, Kim TG, Han HM, Rheu HM, Moon AR. Characterization and anti-gastric ulcer activity of bamboo salts. *J. Food Hyg. Saf.* 13: 252-257 (1998)
- Kim YH, Ryu HI. Elements in a bamboo salt and comparison of its elemental contents with those on other salts. pp. 1-17. In: International Symposium. October 19. SookMyung Women's University, Seoul, Korea. The Pharmaceutical Society of Korea, Seoul, Korea (2001)
- MHW. Food Standard Code. The Ministry of Health and Welfare, Seoul, Korea. pp. 173-177 (2000)
- AOAC. Official Method of Analysis of AOAC Int. 13th ed. Method 532-534. Association of Official Analytical Chemists, Washington DC, USA (1980)
- Schorsch C, Jones MG, Norton IT. Thermodynamic incompatibility and microstructure of milk protein/locust bean gum/sucrose systems. *Food Hydrocolloid* 13: 89-99 (1999)
- Ju IO, Jung GI, Ryu J, Kim YS. Effect of heat treatments on

- physical properties and *in vitro* glucose, bile acid, and cadmium transport retardation of wax gourd (*Benincasa hispida*). Korean J. Food Sci. Technol. 35: 1117-1123 (2003)
21. Korea Food Additives Code. Korea Food Research Institute, Moon Young Sa, Seoul, Korea. p. 510 (2002)
22. Shin HK, Hwang SH, Youn KS. Absorption characteristics and prediction model of ginger powder by different drying methods. Korean J. Food Sci. Technol. 35: 211-216 (2003)
23. Kim SJ, Kim HL, Ham KS. Characterization of *kimchi* fermentation prepared with various salts. Korean J. Food Preserv. 12: 395-401 (2005)
24. Lee GD, Kim SK, Kim JO, Kim ML. Comparison of quality characteristics of salted muskmelon with deep seawater salts, sun-dried salts, and purified salts. J. Korean Soc. Food Sci. Nutr. 32: 840-846 (2003)
25. Whitten KW, Davis RE, Peck L, Stanly GG. General Chemistry. 7th ed. Thomson Press, Toronto, Canada. pp. 479-488 (2003)