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EFFECT OF STORAGE ON THE QUALITY PARAMETERS OF SEA SALT

Summary

Table salt (sodium chloride) is one of the most commonly occurring compounds on Earth. Sea salt is produced by the evaporation of sea water. Because of its origin, this type of salt is distinguished by a natural content of iodine and other valuable minerals (lithium, magnesium, zinc and selenium). Sea salt has a more distinctive taste compared to table salt, so that smaller amounts thereof can be used and, owing to its relatively low sodium content, it is considered to be the healthiest type of salt. The natural sea salt crystals impede the packaging and storage processes and also its dissolution during the technological process or during the food preparation by consumers in domestic conditions. Thus, the objective of the research study was to assess the effect of storage on the quality parameters of crystalline (commercial) and finely ground sea salt. The research material consisted of 6 sea salt samples, which were assessed in a crystalline (CH) and ground (RH) forms immediately after purchase and after 12 months of storage – crystalline (CP) and ground (RP) sea salt samples. The quality assessment of the sea salt samples was made on the basis of the following: water content and water activity, colour assessment, determination of loose (bulk) and tapped density, and static and kinetic angle of repose measured. On the basis of the analyses performed, statistically significant differences were found between the crystalline and ground salt samples taken from the purchased and stored packets; those differences were found in the L* colour parameter (brightness), the value of the Hausner ratio, and the values of the static and kinetic angle of repose. The performed quality assessment of the stored ground sea salt samples might constitute potential recommendations for both the consumers and the food technologists in various branches of the food industry.

Key words: sea salt, water content, water activity, colour, loose (bulk) density, tapped density, static angle of repose, kinetic angle of repose

Introduction

Salt is the most frequently used ingredient in food technology and during home cooking. Consumers pay more and more attention to health properties of the salts used. For this reason, it is suggested to replace traditional table salt by, inter alia, sea salt,

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which is regarded to be a source of additional health promoting ingredients because of the high content of valuable micronutrients. Sea salt available on the Polish market has a form of larger crystals and is sold in unit packets. Halite in the form of crystals is undesirable in food production for it makes packing and storing salt difficult, as does it the dissolution of salt in food products. Salt in the form of crystals should be crushed prior to being used in technological process or during the preparation of food. Thus, consumers have to grind sea salt in order to use it at home.

During the analysis of the issue, it was found that there are only few publications in the reference literature on one of the basic food products, which is salt, including sea salt. Sea salt is an important raw material in food technology and it plays an extremely important role in gastronomy and cuisine. In the reference literature there are no studies on the quality of sea salt nor are those on the effect of storage on the quality parameters of sea salt in crystalline (commercial) and ground forms. From the point of view of managing the transport and storage of sea salt and of using it in food production plants and at home, it is important to have knowledge of the quality parameters of sea salt based on its selected physicochemical properties. A particularly important role during the transport of products on a technological line play the fluidic properties of foodstuffs, estimated on the basis of parameters such as bulk density and static and kinetic angle of repose [11]. Bulk density is a parameter to determine the packing fraction of packets or devices, the efficiency of transport devices; on the basis of bulk density it is possible to estimate the magnitude of frictional forces acting on devices and tanks [11, 13]. On the other hand, the static and kinetic angles of repose determine the size of storage area, storage capacity and silo unloading speed [7, 13].

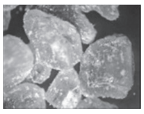
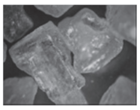
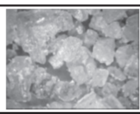
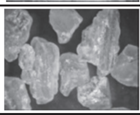
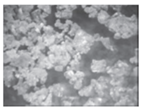
Therefore, the objective of the research study was to assess the effect of storage on the quality parameters of both the crystalline (commercial) sea salt and the sea salt ground under the laboratory conditions.

Material and methods

The research material consisted of 6 sea salts purchased in various places in Poland and abroad. Except for products from the Canary Islands and Denmark, all other salts were purchased in stationary stores. General profile of the products analysed is presented in Tab. 1. There was used information given on the packets and on the manufacturers' websites. Also, there are presented the microscopic images of the tested salts I - VI. Diagram of the research carried out is presented in Fig. 1.

In the research study, there were assessed the samples of: crystalline sea salt taken directly from the packets (CH), salt subjected to grinding (RH), and salt stored in the original packets for a period of 12 months. The salt samples were stored in a room where normal environmental conditions prevailed, i.e. the temperature was 20 ± 2 ºC and the humidity 60 ± 5 %. Only the commercial product, i.e. crystalline salt, was stored and ground after the storage period. The stored products were also examined, i.e. the salt from the packets (CP) and the salt subjected to grinding (RP). Salt was ground with a WŻ-1 type laboratory grinder for 6 s.

Table 1. Profile of material studied
Tabela 1. Charakterystyka badanego materiału

Salt code Kod soli	Country of origin Kraj pochodzenia	Granularity Granulacja	Price/kg Cena/kg [PLN]	Composition Skład
I	Croatia Chorwacja		6.92	Sodium chloride (> 98 %), calcium (< 0.20 %), magnesium (0.19 %), sodium iodide (< 5 mg/kg), naturally occurring iodide, E536 (anti-caking agent) Chlorek sodu (> 98 %), wapń (< 0,20 %), magnez (0,19 %), jodek sodu (< 5 mg/kg), jodek naturalnie występujący, E536 (środek przeciwzbrylający)
II	Greece Grecja		3.87	Sodium chloride (99.5 %), 3.9 ± 1.3 mg/kg potassium iodate (enriching agent), E536 (anti-caking agent), iodine (23100 μg/kg) / Chlorek sodu (99,5 %), 3.9 ± 1.3 mg/kg jodanu potasu (substancja wzbogacająca), E536 (środek przeciwzbrylający), jod (23100 μg/kg)
III	Greece / Grecja (Mediterranean Sea) (Morze Śródziemne)		8.57	Unrefined, 100 % of coarse-grained sea salt, no anti-caking agents contained therein / Nierafinowana, 100 % soli morskiej grubo mielonej, nie zawiera substancji przeciwzbrylających
IV	Canary Islands Wyspy Kanaryjskie (Fuertaventura)		21	Natural, no additives Naturalna, bez dodatków
V	Origin unknown Pochodzenie niez- nane		7.90	Iodized, potassium iodate Jodowana, jodan potasu (26.0 ÷ 33.7 mg/kg salt / soli)
VI	Denmark Dania		172.52	Sodium chloride (95 %), other minerals (5 %), naturally occurring iodine Chlorek sodu (95 %), inne związki mineralne (5 %), naturalnie występujący jod

Source / Źródło: the authors' own study based on information placed on unit packets / opracowanie własne na podstawie informacji zawartych na opakowaniach jednostkowych.

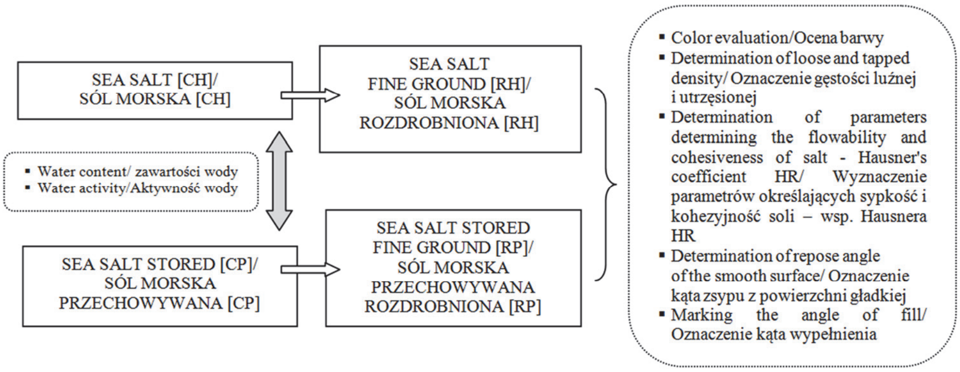


Fig. 1. Research flow chart
Rys. 1. Schemat przebiegu badań
Source / Źródło: the authors' own study / opracowanie własne.

The water content in the samples was determined by thermal drying at a temperature of 403.15 K (130 ºC) under the ambient pressure for 5 h [14]. There were analysed the samples of crystalline salt from the packets (CH) and those of crystalline salt after storage (CP). The water activity was determined in an AquaLab 4TE apparatus, AS4 2.14.0 2017 version (Decagon Devices, Inc., USA), with an accuracy of ± 0.0003 at a temperature of 293 K (20 ºC).

The instrumental determination of the product colours was performed using a Konica-Minolta CR 400 colorimeter (Konica Minolta, Japan) for the standard 2º observer and D65 illuminate. The colour measurements were made in a CIE LAB colour space, where L* determines the brightness of raw materials and extrudates (on a scale of 0 ÷ 100), a* colour index is the balance of green (-100) and red (+100) and b* colour index is the balance of blue (-100) and yellow (+100).

The characterisation of the selected quality parameters was carried out on the basis of determining the bulk and tapped density, which are the basic discriminants necessary to determine the Hausner ratio and the Carr index [2, 8, 9].

The evaluation of the products included the determination of the static angle of repose [6, 9] and of the kinetic angle of repose by a tilted surface method using a constant volume of the product [3, 4].

The results obtained are presented as a mean value of three replications. The statistical calculations were performed using PQStat 1.8.0.476 and Statistica 12 packages. In order to determine the differences between the salt groups examined, an analysis of variance (ANOVA) was used. To check the significance of differences between individual groups, a Tukey's post-hoc test with the significance level of $p \leq 0.05$ was applied. To evaluate the differences between the means, a Student's t-test was used and a multivariate cluster analysis was performed.

Results and discussion

Water content and activity are the basic parameters to indicate the directions of chemical, physical and microbiological changes to shape the quality and stability of food products. The water contained in the salt is mostly structural water, which is inaccessible to microorganisms and remains in a state of chemical inactivity. The low value of water activity of salt, including sea salt, explains its use as a food preservative.

Based on the assessment of the initial water content in sea salts taken directly from the packets (CH), it was found that salt IV from the saltworks in Fuerteventura (Salinas del Carmen) was characterised by the highest water content and a high water activity. Probably the high values of the parameters assessed could have resulted from the composition of sea salt (Tab. 2). The packet of sea salt from Fuerteventura lacks the composition of the product; the proportion of sodium chloride is not stated. With a lower content of sodium chloride and the co-occurrence of calcium and magnesium salts, the product can quickly become hygroscopic until achieving the flow effect, which explains an increase in the water content in the salt stored for a period of 12 months. Sea salt VI obtained from saltworks in Denmark was also characterised by a high content of water. When assessing the water content in the stored products (CP), it was found that, except for salts IV and V, the water content decreased in the remaining products after the storage process. Thus, the obtained values of changed water content indicated adequate barrier properties of the packet packaging.

Table 2. Water content in and water activity of crystalline sea salt (not stored and stored)
Tabela 2. Zawartość i aktywność wody soli morskiej krystalicznej (nieprzechowywanej i przechowywanej)

Salt code Kod soli	Crystalline sea salt / Sól morska krystaliczna			
	Water content / Zawartość wody [g/100 g d.m. / s.m.]		Water activity Aktywność wody [-]	
	CH	CP	CH	CP
I	0.5204	0.4739	0.6432	0.3700
II	0.4165	0.0756	0.3980	0.3145
III	0.0677	0.0366	0.3799	0.3221
IV	3.7801	4.7373	0.5112	0.6254
V	0.0182	0.0238	0.3477	0.3782
VI	2.2304	1.9388	0.6260	0.3449

Explanatory notes / Objaśnienia:
CH – sea salt taken directly from the packet, not stored / sól morska pobrana bezpośrednio z opakowania, nieprzechowywana; CP – seal salt stored / sól morska przechowywana.
Source / Źródło: the authors' own study / opracowanie własne.

The water activity of the sea salts II, III and V taken directly from the packets was characterised by a similar low level and ranged between 0.3477 ÷ 0.3980 (Tab. 2). On the other hand, the samples of sea salts I, IV and VI from the saltworks in Croatia, Fuerteventura and Denmark, respectively, were characterised by water activity values between 0.5112 ÷ 0.6432.

On the basis of the instrumental colour measurement, it was found that the brightness of the tested sea salts taken directly from the packets (CH) and expressed by L* parameter was clearly in the range between 63.68 ÷ 84.14 (Tab. 3). The colour of sea salt II (CH) was the closest to the white colour, whereas sea salt I (CH) had the most pronounced gray colour. The brightness of the stored sea salts (CP) changed during storage. The sea salts I and VI showed an increase in the brightness, while a decrease in the L* parameter was found in other products assessed (Tab. 3). It was also found that the grinding process increased the L* brightness parameter of the assessed the sea salts I - VI.

Table 3. Colour assessment of crystalline and ground sea salt (not stored and stored)
Tabela 3. Ocena barwy soli morskiej krystalicznej i rozdrobnionej (nieprzechowywanej i przechowywanej)

Salt code Kod soli	Sea salt / Sól morska											
	Crystalline / Krystaliczna						Ground / Rozdrobniona					
	CH			CP			RH			RP		
	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
I	63.68	-0.17	1.06	74.60	-0.32	0.95	93.75	-0.19	1.31	94.51	-0.16	1.65
II	84.14	-0.23	1.66	78.18	-0.07	0.23	95.37	-0.22	1.55	94.53	-0.13	1.12
III	76.22	-0.11	0.19	71.33	-0.11	0.43	95.93	-0.16	0.57	95.10	-0.16	0.77
IV	69.90	-0.06	0.68	68.26	-0.05	0.78	93.12	-0.15	1.23	95.44	-0.14	1.34
V	77.90	-0.15	0.81	77.52	-0.20	0.69	96.85	-0.14	0.72	95.63	-0.15	1.39
VI	77.68	-0.32	1.08	78.82	-0.40	1.78	92.56	-0.30	2.91	91.95	-0.19	4.33

Explanatory notes / Objaśnienia:
CH – crystalline sea salt, not stored / sól morska krystaliczna, nieprzechowywana; CP – crystalline sea salt, stored / sól morska krystaliczna, przechowywana; RH – ground sea salt, not stored / sól morska rozdrobniona, nieprzechowywana; RP – ground sea salt, stored / sól morska rozdrobniona, przechowywana.
Source / Źródło: the authors' own study / opracowanie własne.

Comparing the value of $p < 0.000001$ in the one-way analysis of variance with the $\alpha = 0.05$ significance level, it was found that the mean value of L* parameter of the sea salts tested varied. Using a post-hoc Tukey's test and comparing the p values in the test with the $\alpha = 0.05$ significance level, it was found that no significant differences were only between the salt taken from the packets (CH) and the stored salt (CP). In the remaining salts, the average level of the L* lightness attribute was significantly different.

The range of a* parameter in CH salts was between -0.32 ÷ -0.06, in CP salts between -0.40 ÷ -0.05, in RH salts between -0.30 ÷ 0.14 and in RP salts between -0.19 ÷ -0.13. The a* parameter indicates the colour saturation from green (negative values) to red (positive values). Negative values of the green colour shape the colour of the final product. In this case a* parameter indicated the absence of other compounds that could affect the appearance of such shades in the salts tested. Based on the statistical analysis, there were no significant differences in a* parameter as regards different types of CH, CP, RH and RP salts. Thus, it was found that both the storage and the grinding process did not significantly affect the value of a* parameter assessed.

The value of b* parameter for the CH products ranged between 0.19 ÷ 1.66, for the CP products between 0.23 ÷ 1.78, for the RH products between 0.72 ÷ 2.91 and for the RP products between 0.77 ÷ 4.33. The b* parameter indicates the colour saturation from blue (-) to yellow (+). As in the case of a* parameter, based on the statistical analysis, there were no significant differences in b* parameter between the different types of CH, CP, RH and RP salts.

Bulk and tapped density was another assessed parameter of sea salt quality related to the trading of loose goods (Tab. 4). Bulk density is the ratio of the mass of the particles and the volume occupied by them, including the free volume. It is not constant as it depends on the particle distribution, their shape and arrangement, and it affects the packing possibilities of the product [1, 5]. On the basis of the present research, it was found that product I had the highest bulk and tapped density of the crystalline salts taken directly from the packets (CH) (Tab. 4). For the remaining products, the value of the parameter evaluated was very similar and ranged between 0.76 ÷ 1.17 g/cm^3 (Tab. 4). When assessing the stored unground salts (CP), a decrease was reported in the value of bulk and tapped density of the majority of products. Only for sea salt III a slight increase in the parameters assessed was found, despite the decrease in the water content in and water activity of the product stored (Tab. 2). Characterising the bulk and tapped density of the ground products taken from the packets (RH) and stored (RP), lower values of those parameters were reported because of the smaller size of particles. As for the ground salt taken directly from the packets (RH), the value of its bulk density was between 1.24 ÷ 1.46 g/cm^3 and the tapped density between 1.24 ÷ 1.46 g/cm^3. On the other hand, in all the ground sea salts assessed after storage (RP) a decrease was found in both the bulk and the tapped density compared to the ground product before storage (RH). Comparing the $p = 0.026623$ value in the one-way analysis of variance with the $\alpha = 0.05$ significance level, it was found that the mean value of the tapped density of the salts analysed was different. To distinguish between the salts in terms of tapped density, a post-hoc Tukey's test was applied. Determined for each pair of comparisons, the least significant difference (LSD) was the same and amounted to 0.230531. Comparing the LSD value with the mean difference value, it was found that significant differences existed only between the CP salt and RH ground salt from the packets. As of the remaining salts, the average tapped density was not significantly different. The same conclusion was drawn when comparing the p values in the post-hoc test with the $\alpha = 0.05$ significance level.

Table 4. Bulk and tapped density and Hausner ratio of crystalline and ground sea salt (not stored and stored)
Tabela 4. Gęstość nasypowa luźna i utrzęsiona oraz współczynnik Hausnera soli morskiej krystalicznej i rozdrobnionej (nieprzechowywanej i przechowywanej)

Salt code Kod soli	Parameter Parametr	Sea salt / Sól morska			
		CH	CP	RH	RP
I	ρ_L [g/cm^3]	1.26	1.11	1.01	0.83
	ρ_T [g/cm^3]	1.28	1.25	1.41	1.09
	HR	**1.02**	**1.13**	**1.40**	**1.33**
II	ρ_L [g/cm^3]	1.14	1.14	0.99	0.91
	ρ_T [g/cm^3]	1.17	1.15	1.32	1.24
	HR	**1.03**	**1.01**	**1.33**	**1.36**
III	ρ_L [g/cm^3]	1.09	1.18	1.05	0.97
	ρ_T [g/cm^3]	1.11	1.32	1.26	1.17
	HR	**1.02**	**1.12**	**1.20**	**1.20**
IV	ρ_L [g/cm^3]	0.99	0.85	0.98	0.83
	ρ_T [g/cm^3]	1.17	0.89	1.30	1.15
	HR	**1.18**	**1.05**	**1.33**	**1.39**
V	ρ_L [g/cm^3]	1.12	1.04	1.10	0.87
	ρ_T [g/cm^3]	1.14	1.09	1.46	1.18
	HR	**1.02**	**1.04**	**1.33**	**1.36**
VI	ρ_L [g/cm^3]	0.76	0.66	0.93	0.84
	ρ_T [g/cm^3]	0.82	0.76	1.24	1.13
	HR	**1.08**	**1.16**	**1.33**	**1.35**

Explanatory notes / Objaśnienia:
ρ_L – bulk (loose) density / gęstość luźna, ρ_T – tapped densisty / gęstość utrzęsiona, HR – Hausner ratio / współczynnik Hausnera. Other explanatory notes as in Tab. 3. / Pozostałe objaśnienia jak pod tab. 3.
Source / Źródło: the authors' own study / opracowanie własne.

The values of Hausner ratio (HR) for the tested sea salts I - VI (Tab. 4) were compared with the classification proposed by Samborska et al. [10]. The HR value informs about the consistency of products related to the cohesive forces. It was found that the unground salts taken from the packets (CH) and the salts after storage (CP) were characterised by HR ranging between 1.02 ÷ 1.18. The materials showing HR below 1.2 are referred to as low cohesion products. In the case of the ground sea salts taken from the packets (RH) and the stored ground salts (RP), an increase was found in the value of the HR coefficient. The ground salts tested were characterised by a medium cohesiveness value (HR = 1.2 ÷ 1.4). Comparing the p values in the post-hoc Tukey's test with the $\alpha = 0.05$ significance level, it was found that no significant differences existed only between the HR values of the CP and CH products and the RP and RH products. In the remaining cases, there were statistically significant differences between the values of the HR parameter evaluated.

Another parameter to characterise the quality of sea salts was a static angle of repose; it defines the storage area and storage capacity the product would occupy. The static angle of repose is defined as an angle between the generatrix and the base of the cone of a pile formed when the powder is freely poured; it is another flow indicator of the product [12]. It is assumed that with the increasing value of the angle, the flow of the product is lower, and the products with an angle above 50º are characterised by low fluidic properties in contrast to free-flowing products, the angle of repose of which is smaller than 40º [7]. Based on the assessment of the angle of repose, it was found that all assessed sea salts were characterised by poor flow properties. The products stored and subjected to grinding had a higher value of the static angle of repose (Tab. 5). Comparing the p value < 0.000001 in the one-way ANOVA with the $\alpha = 0.05$ significance level, it was found that the mean value of the angle of embankment of the investigated sea salts was different. Comparing the p values in the post-hoc Tukey's test with the $\alpha = 0.05$ significance level, it was found that the statistically significant differences existed between the angle of repose of all the assessed variants of the tested sea salts I - VI.

The kinetic angle of repose (sliding angle) is the minimum angle formed between the horizontal plane and the top layer of the inclined surface, at which the sliding of the loose material begins. Therefore, the kinetic angle of repose of sea salts is an important quality distinguishing feature. The value of the kinetic angle of repose depends on the mineral composition, degree of coating of the particles and their mutual arrangement (packing ratio). On the basis of the research conducted, it was found that as for the not stored crystalline sea salts (CH), the value of the sliding angle ranged between 23º ÷ 48º, whereas for the crystalline stored products (CP) was between 23º ÷ 34º. Thus, it was found that the storage process of the crystalline sea salts caused the value of the assessed parameters to decrease (Tab. 5). Based on the analysis of the results of the sliding angle carried out by the post-hoc Tukey's test, it was found that there were no statistically significant differences between the crystalline sea salt taken from the packets (CH) and the stored salt (CP). As for the remaining salts, the mean value of the kinetic angle of repose from the smooth surface was significantly different.

Table 5. Values of static angle of repose and kinetic angle of repose from surface of crystalline and ground sea salt (not stored and stored)
Tabela 5. Wartość kąta nasypu i kąta zsypu z powierzchni gładkiej soli morskiej krystalicznej i rozdrobnionej (nieprzechowywanej i przechowywanej)

Salt code Kod soli	Static angle of repose Kąt nasypu [°]				Kinetic angle of repose Kąt zsypu [°]			
	CH	CP	RH	RP	CH	CP	RH	RP
I	53.19	43.92	57.03	51.38	29	20	41	42
II	51.48	41.68	57.95	50.37	27	22	47	45
III	51.39	42.42	55.26	49.69	23	21	75	55
IV	52.63	45.26	57.44	51.78	48	34	53	60
V	51.57	42.55	58.05	50.72	29	16	78	57
VI	52.27	47.29	58.78	52.78	34	30	43	62

Explanatory notes as in Tab. 3. / Objaśnienia jak pod tab. 3.
Source / Źródło: the authors' own study / opracowanie własne.

Table 6. Parameter values received by Student's t-test and referring to CH and RH salts before storing
Tabela 6. Wartość parametrów testu t-Studenta dotyczące soli nieprzechowywanych CH i RH

Parameter / Parametr	CH	RH	t	df	P
Water content Zawartość wody	1.17223	1.17223	0	10	1
Water activity Aktywność wody	0.48434	0.48434	0	10	1
Colour / Barwa: L*	74.91889	94.59611	-6.56812	10	**0.000063***
Colour / Barwa: a*	-0.175	-0.19389	0.41812	10	0.684697
Colour / Barwa: b*	0.91444	1.38111	-1.18292	10	0.264202
Bulk loose density Gęstość luźna [g/cm^3]	1.06	1.01	0.67791	10	0.51321
Tapped density / Gęstość utrzęsiona [g/cm^3]	1.115	1.33167	-2.98335	10	**0.013729***
Hausner ratio Współczynnik Hausnera	1.05653	1.31942	-6.99698	10	**0.000037***
Static angle of repose Kąt nasypu	52.08833	57.41833	-9.22631	10	**0.000003***
Kinetic angle of repose Kąt zsypu	31.66667	56.16667	-3.24305	10	**0.008824***

Explanatory notes / Objaśnienia:
df – degrees of freedom / stopnie swobody; p – probability / prawdopodobieństwo. Other explanatory notes as in Tab. 3. / Pozostałe objaśnienia jak pod tab. 3.
Source / Źródło: the authors' own study / opracowanie własne.

The value of the kinetic angle of repose for the ground products (RH) ranged between 41º ÷ 78º, while for the stored ground products (RP) between 42º ÷ 62º. On the basis of the assessment, it was found that the grinding process increased the value of the sliding angle, which may probably resulted from a higher value of the friction coefficient between the fragmented sample and the smooth surface of which the test material was poured.

On the basis of the research results, an attempt was made to statistically evaluate (using a Student's t-test) the relationship between the tested products in the crystalline form (CH) and fragmented form (RH) before storage (Tab. 6).

In the case of the stored crystalline (CP) and fragmented (RP) products, based on the data analysis performed by Student's t-test, it was found that there were statistically significant differences in the mean L* parameter, Hausner ratio and angles of repose (Tab. 7).

Table 7. Parameter values received by Student's t-test and referring to CP and RP salts after storage
Tabela 7. Wartość parametrów testu t-Studenta dotyczące soli przechowywanych CP i RP

Parameter / Parametr	CP	RP	t	df	P
Water content Zawartość wody	1.21433			10	
Water activity Aktywność wody	0.39251			10	
Color / Barwa: L*	74.78667	94.52556	-10.873	10	**0.000001***
Color / Barwa: a*	-0.19056	-0.155	-0.6098	10	0.555621
Color / Barwa: b*	0.81056	1.76778	-1.6757	10	0.124725
Bulk (loose) density Gęstość luźna [g/cm^3]	0.99667	0.875	1.4231	10	0.185153
Tapped density / Gęstość utrzęsiona [g/cm^3]	1.07667	1.16	-0.9264	10	0.376038
Hausner ratio Współczynnik Hausnera	1.08337	1.3282	-7.018	10	**0.000036***
Static angle of repose Kąt nasypu	43.85293	48.89679	-4.8127	10	**0.00071***
Kinetic angle of repose Kąt zsypu	23.83333	53.5	-6.8522	10	**0.000044***

Explanatory notes as in Tab. 6. / Objaśnienia jak pod tab. 6.
Source / Źródło: the authors' own study / opracowanie własne.

In order to compare the relationships between the assessed salts I - VI in the not stored crystalline (CH) and ground (RH) products, a cluster analysis was used, which allowed to distinguish two groups (clusters) in the crystalline products and two groups in the ground products (Fig. 2). The first group comprised the sea salts I (CH) and IV

(CH). In the second group a similarity was revealed to exist among the sea salt samples II (CH), III (CH), V (CH) and VI (CH). Based on the multivariate analysis of clusters in the not stored ground products, it was found that the sea salts I (RH), II (RH), IV (RH) and VI (RH) were the most similar to each other. Thus, as for the stored products, it was found that the grinding process had the strongest impact on the change in the parameters of the sea salts II (RH) and VI (RH) (Tab. 6).

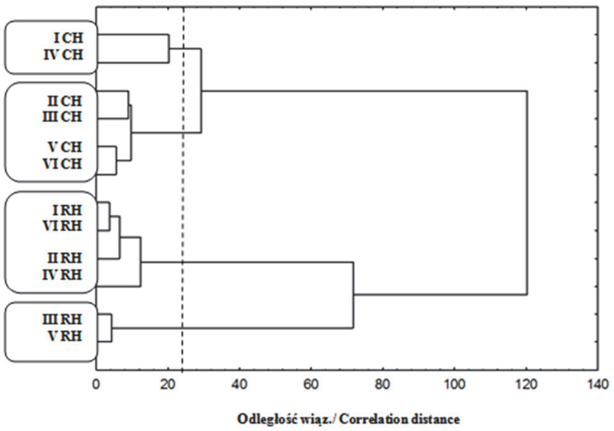


Fig. 2. Tree diagram showing relationship between determined quality parameters for not stored sea salt – crystalline (CH) and ground (RH)

Rys. 2. Diagram drzewa odzwierciedlający powiązania pomiędzy wyznaczonymi parametrami jakości soli morskiej nieprzechowywanej – krystalicznej (CH) i rozdrobnionej (RH)

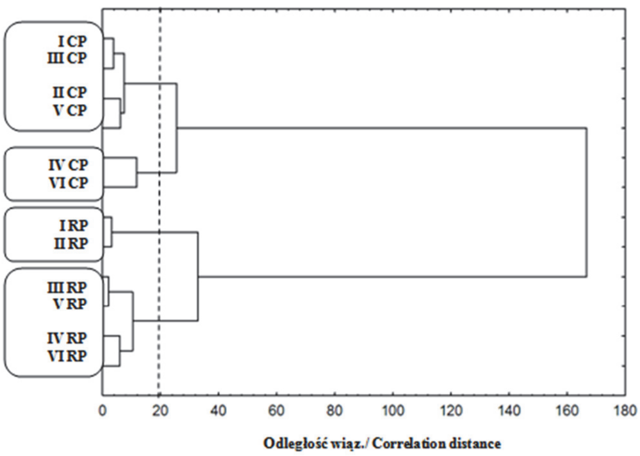


Fig. 3. Tree diagram showing the relationship between determined quality parameters for stored sea salt – crystalline (CP) and ground (RP)

Rys. 3. Diagram drzewa odzwierciedlający powiązania pomiędzy wyznaczonymi parametrami jakości soli morskiej przechowywanej – krystalicznej (CP) i rozdrobnionej (RP)

In the case of the stored crystalline (CP) and ground (RP) products, two clusters were also distinguished in the crystalline products and two clusters in the ground products (Fig. 3). The first concentration in the stored crystalline products comprised the sea salts I (CP), II (CP), III (CP) and V (CP). In the second cluster a similarity was revealed to exist among the sea salts IV (CP) and VI (CP). Based on the analysis conducted, it was proved that the process of storage and fragmentation had the strongest impact on the change in the parameters of the sea salts III (RP) and V (RP) (Fig. 3).

Conclusions

1. Based on the assessment of water content and water activity, it was found that the storage process caused the assessed parameters of the sea salts I - III and VI to decrease. On the other hand, as regards the sea salts IV and V, there was reported an increase in the water content and water activity after 12-month storage.
2. Based on the assessment of the L* brightness parameter, no statistically significant differences were found between the not stored and stored crystalline salts. On the other hand, in the fragmented products, the level of the L* colour attribute was statistically significant for all the variants tested.
3. On the basis of the Hausner ratio value, it was found that the crystalline products taken from the packets and stored were characterised by low consistency. On the other hand, based on the grinding process of the sea salts I - VI assessed, it was possible to classify them as materials characterised by a medium cohesiveness.
4. The grinding process resulted in an increase in the value of the static and kinetic angle of repose and, based on the obtained values of those parameters, all the assessed sea salts were classified as the products of poor flow properties.

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WPŁYW PRZECHOWYWANIA NA PARAMETRY JAKOŚCI SOLI MORSKIEJ

S t r e s z c z e n i e

Sól spożywcza (chlorek sodu) to jeden z najpowszechniej występujących związków na kuli ziemskiej. Sól morska pozyskiwana jest poprzez odparowanie wody morskiej. Z uwagi na pochodzenie ten rodzaj soli odznacza się naturalną zawartością jodu i innych cennych związków mineralnych (litu, magnezu, cynku, selenu). Sól morska ma bardziej wyrazisty smak niż sól spożywcza, co sprawia, że używana jest w mniejszych ilościach, a ze względu na stosunkowo małą zawartość sodu uważa się ją za najzdrowszą. Naturalne kryształy soli morskiej utrudniają proces pakowania i przechowywania, jak również jej rozpuszczanie w procesie technologicznym oraz podczas przygotowania potraw przez konsumentów w warunkach domowych. W związku z powyższym celem niniejszej pracy była ocena wpływu przechowywania na parametry jakości soli morskiej krystalicznej (handlowej) i rozdrobnionej w warunkach laboratoryjnych. Materiałem badanym było 6 prób soli morskiej, które oceniono w postaci krystalicznej (CH) oraz rozdrobnionej (RH) bezpośrednio po zakupie oraz po przechowywaniu przez 12 miesięcy – sól morska krystaliczna (CP) oraz sól morska rozdrobniona (RP). Ocenę jakości prób soli określono na podstawie: zawartości i aktywności wody, oceny barwy, oznaczenia gęstości nasypowej luźnej i utrzęsionej, pomiaru kąta nasypu oraz kąta zsypu z powierzchni gładkiej. Na podstawie przeprowadzonych badań stwierdzono statystycznie istotne różnice między próbami soli krystalicznej i rozdrobnionej, pobranymi z opakowania po zakupie jak i przechowywanymi, pod względem parametru barwy L* (jasności), wartości współczynnika Hausnera oraz wartości kąta nasypu i zsypu z powierzchni gładkiej. Przeprowadzona ocena jakości prób soli morskiej przechowywanych i rozdrobnionych może stanowić przyszłe rekomendacje zarówno dla konsumentów, jak i technologów żywności poszczególnych branż przemysłu spożywczego.

Słowa kluczowe: sól morska, zawartość wody, aktywność wody, barwa, gęstość nasypowa luźna, gęstość nasypowa utrzęsiona, kąt nasypu, kąt zsypu