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STUDY OF THE CHEMICAL COMPOSITION AND FUNCTIONAL-TECHNOLOGICAL PROPERTIES OF *SALICORNIA EUROPAEA* PLANT POWDER

Annotation: *The aim of this study was to investigate the physicochemical, mineral, and functional-technological properties of powder obtained from the plant Salicornia europaea collected near the village of Kumkent, Suzak district, Turkestan region, and to scientifically substantiate the possibility of its use as a natural salt substitute in food products. The results showed that the moisture content of the plant raw material was 2.61%, while the total ash content was 15.17%. Mineral composition analysis revealed the predominance of sodium (Na) (32.89%) and chlorine (Cl) (33.51%), together with Mg, Si, K and Ca elements. The powder contained 2.41% total phenolic compounds and 1.37% flavonoids. Sieve analysis showed that the main fraction ranged from 0.25 to 0.5 mm, while SEM analysis revealed a porous microstructure of the particles. The swelling coefficient was 3.2, indicating high water-binding capacity. Safety assessment confirmed that the levels of toxic elements, pesticide residues and microbiological indicators complied with regulatory requirements. Unlike our previous study, which focused on the application of Salicornia europaea as a partial salt substitute in meat chips, the present work provides a comprehensive characterization of the powder itself. In addition to confirming its mineral composition, this study presents new data on moisture and ash content, biologically active compounds, particle-size distribution, microstructure, swelling capacity and safety indicators. These findings expand the current knowledge of the functional-technological properties of Salicornia europaea powder and substantiate its potential use as a natural salt substitute and functional food ingredient. The obtained results demonstrate that Salicornia europaea powder is a promising natural salt substitute and functional ingredient for use in the food industry.*

Key words: *Salicornia europaea, plant powder, salt substitute, mineral composition, phenolic compounds, flavonoids, microstructure, functional properties.*

Introduction

Nowadays, the problem of proper nutrition of the population and improving the quality of food products is one of the most important scientific directions in the food industry. In recent years, special

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attention has been paid to the problem of reducing the amount of table salt in food products. Scientific studies have proven that excessive consumption of sodium chloride increases the risk of developing cardiovascular diseases, arterial hypertension and kidney diseases [1, 2]. In this regard, reducing the amount of table salt in the production of food products and using natural salt substitutes instead is one of the current scientific problems [3].

In our previous study [10], *Salicornia europaea* was investigated as a natural partial substitute for table salt in meat chips, and the optimal ratio of table salt to *Salicornia* powder was determined based on the organoleptic characteristics of the finished product. However, that study focused primarily on the formulation of meat chips rather than on the comprehensive characterization of *Salicornia* powder itself. Therefore, the present study extends our previous research through a comprehensive investigation of the physicochemical composition, biologically active compounds, particle-size distribution, microstructure, functional-technological properties, and safety indicators of *Salicornia europaea* powder, thereby providing a scientific basis for its application as a natural salt substitute and functional food ingredient.

One of the promising plant raw materials for use as a salt substitute is Salicornia europaea. This plant belongs to the group of halophytic plants that grow in saline soils and is characterized by a high content of mineral elements, especially sodium and potassium [4]. Scientific studies show that Salicornia contains phenolic compounds, flavonoids, mineral elements and other biologically active substances [5]. Such a composition provides the antioxidant properties of the plant and allows it to be used as a functional food ingredient [6].

The potential of Salicornia in food production has been widely discussed in the literature. Some studies have shown that the powder of this plant can replace part of the table salt in food products, reducing the sodium content while maintaining the organoleptic properties of the product [7]. In addition, the minerals and biologically active compounds contained in Salicornia contribute to increasing the nutritional and biological value of food products [8].

In recent years, special attention has been paid to the development of low-salt products in food technology. In this direction, the use of functional ingredients of plant origin allows to increase the nutritional value of the product while maintaining its structural-mechanical and organoleptic properties [9]. The use of natural salt substitutes is especially important in the production of meat products [10].

In Kazakhstan, the Salicornia plant grows mainly on saline soils, in desert and semi-desert areas. Our previous study [10] demonstrated that Salicornia europaea growing near the village of Kumkent, Sozak district, Turkestan region, is characterized by a high content of sodium and chlorine. These findings indicate its potential for use as a natural salt substitute in food production.

In this regard, the purpose of the research work is to study the chemical composition and functional and technological properties of powder obtained from the Salicornia plant, as well as to scientifically substantiate the possibility of its use as a natural salt substitute component in the production technology of low-salt meat chips.

Research methods

The object of the study was the powder obtained from the aboveground part of the halophyte plant Salicornia europaea, which grows in saline soils. The plant samples were collected from the saline soil zone of the Moyinkum sandy valley near the village of Kumkent, Sozak district, Turkestan region, Republic of Kazakhstan. Our previous study [10] demonstrated a high sodium and chlorine content in Salicornia europaea collected from this region. The collected plant samples were cleaned of mechanical impurities in laboratory conditions and dried at a temperature of 40-50°C. The dried plant material was crushed using a porcelain mortar and ground to a homogeneous powder.

The determination of the physicochemical parameters of the plant powder was carried out using standard laboratory methods. The moisture content of the raw material was determined by the drying method, and the ash content was determined by the method of calcination in a muffle furnace. The elemental (mineral) composition of the Salicornia europaea plant powder was determined in the scientific research laboratory «Building Materials and Structures» of the M. Auezov South Kazakhstan University. The analysis was carried out using the method of energy-dispersive X-ray spectroscopy (SEM-EDS) combined with a scanning electron microscope. This method allows to determine the qualitative and quantitative composition of the elements in the studied sample. According to the results of the study, the main elements in the sample were oxygen (O), sodium

(Na), chlorine (Cl), carbon (C), sulfur (S) and potassium (K), their amounts were calculated in mass percent.

Spectrophotometric methods were used to determine the amount of biologically active compounds in Salicornia powder. The amount of total phenolic compounds was determined using the Folin–Chocalteu reagent, and the amount of flavonoids was determined by a spectrophotometric method based on the complexation reaction with aluminum chloride. Measurements were carried out using a spectrophotometer, and the percentage of compounds was calculated based on the results obtained.

The determination of the fractional composition of the powder was carried out by the method of sieve analysis. During the study, a set of laboratory sieves with cell sizes of 1.25; 0.63 and 0.315 mm was used. A 100 g sample of the powder was sieved for 10 minutes using a mechanical vibrating sieve. The mass of each fraction was measured on an analytical balance (measurement accuracy ±0.01 g), and their percentage was calculated.

The microstructure of the powder particles was studied using a scanning electron microscope (SEM). The shape, surface structure and porosity of the particles were analyzed based on microphotographs taken at different magnifications (×50, ×100, ×250, ×500 and ×1000). The obtained microphotographs were processed using the ImageJ program for morphometric analysis, and the equivalent diameters of the particles were determined. Based on these data, the characteristic particle sizes d10, d50 and d90 were calculated.

In order to evaluate the functional and technological properties of Salicornia powder, its water-binding capacity was studied. For this, the swelling coefficient of the powder was determined. During the experiment, a certain amount of powder was mixed with distilled water, and then its water-absorption and retention capacity were evaluated using the centrifugation method.

The safety indicators of plant powder were determined in the Research Laboratory for Assessment of Quality and Safety of Food Products of Almaty Technological University. The studies were conducted in accordance with the requirements of the Technical Regulation TR TS 021/2011 "On Food Safety". The content of toxic elements was determined according to the standards GOST 30178-96 and GOST 32689.1-2014. The residual amounts of pesticides were studied according to the methodology of GOST 32689.1-2014. Microbiological indicators were determined according to the standards GOST 10444.12-2013, GOST 10444.15-94, GOST 31747-2012 and GOST 31659-2012.

The obtained experimental results were analyzed using statistical processing methods, allowing us to evaluate the physicochemical, mineral, and functional-technological properties of Salicornia plant powder.

Research results

The study investigated the physicochemical, mineral, and functional-technological properties of powder obtained from the plant Salicornia europaea. The results showed that the plant powder is a promising raw material for use in the food industry, especially in the development of low-salt products.

First, one of the main indicators characterizing the quality of the studied plant raw materials was determined – humidity. According to the results of the study, the humidity of the plant raw materials was 2.61%. This indicator meets the requirements for the storage of plant raw materials and ensures their stability during storage. Low humidity allows you to prevent microbiological deterioration of plant raw materials and maintain their quality for a long time.

One of the important indicators characterizing the mineral composition of plant raw materials is the ash content. According to the results of the study, the total ash content of the Salicornia plant was 15.17%. This indicator indicates that the plant accumulates a high amount of mineral elements. This feature is characteristic of halophytic plants growing in saline soils.

The mineral composition was determined using the scanning electron microscope-combined energy dispersive X-ray spectroscopy (SEM-EDS) method. According to the results of the study, the plant was dominated by sodium and chlorine elements (Fig. 1-2, Table 1). The sodium content was 32.89%, and the chlorine content was 33.51%. In addition, elements such as magnesium (1.80%), silicon (1.32%), potassium (1.94%) and calcium (0.74%) were found in the plant. The high content of sodium and chlorine indicates that this plant is a salt-accumulating halophyte and proves its potential use as a natural salt substitute in food products.

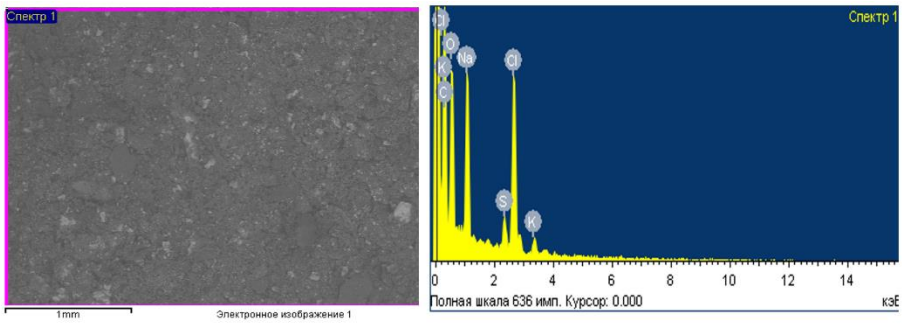


Figure 1 – Microstructure of Salicornia europaea powder

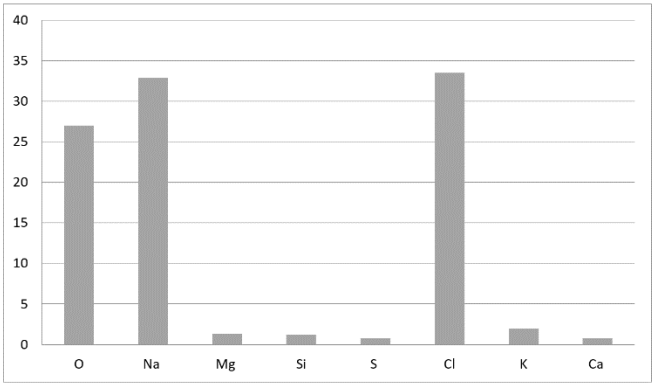


Figure 2 – Mineral composition of Salicornia europaea powder

Table 1 – Composition of mineral elements in the aboveground part of Salicornia europaea

Element	Mass fraction, %
O	27,02
Na	32,89
Mg	1,80
Si	1,32
S	0,78
Cl	33,51
K	1,94
Ca	0,74
Total	100,00

The content of extractive substances is also one of the important indicators in assessing the quality of plant raw materials. According to the results of the study, the highest content of extractive substances was determined when using 50% ethyl alcohol (29.42%). At the same time, when extracting with water, this indicator was 25.52%, and when using 70% ethyl alcohol, it was 20.36%. These results indicate that the plant contains a sufficient amount of biologically active substances.

The content of biologically active compounds in Salicornia europaea powder is given in Table 2. According to the results of the study, the plant contains phenolic compounds and flavonoids. These compounds characterize the antioxidant and biologically active properties of the plant. According to the results of quantitative analysis, the content of phenolic acids is 2.41%, and flavonoids is 1.37%. The presence of phenolic compounds indicates the antioxidant properties of the plant powder and increases its potential for use in the production of functional food products.

Table 2 – Biologically active compounds and extractive content of Salicornia europaea powder

Indicator	Solvent (extractant)	Size, %
Total phenols	–	2,41
Flavonoids	–	1,37
Extractives	Ethyl alcohol (70 %)	20,36
Extractives	Ethyl alcohol (50 %)	29,42
Extractives	Water	25,52

The dispersion composition of plant powder directly affects the uniform distribution of ingredients in food systems. According to the results of sieve analysis, it was determined that the main part of the particles of Salicornia europaea powder consists of medium and fine fractions. The majority of the powder belongs to the 0.25-0.5 mm fraction (42.7%). At the same time, the share of the 0.5-1 mm fraction was 24.5%, and the share of particles smaller than 0.25 mm was 26.5%. The large fraction (>1 mm) was relatively small, its share was 6.3%. The results obtained indicate that the powder has a finely dispersed structure, which allows for uniform distribution in food systems.

The microstructure of the powder of Salicornia europaea was studied using an electron microscope at different magnification levels (Figure 3-4). The results of the study showed that the powder particles are irregular in shape and have different sizes. At low magnification levels (×50 and ×100), the general structure of the powder particles and their arrangement with each other are observed. At this level, large aggregates of particles and their uniform distribution are visible.

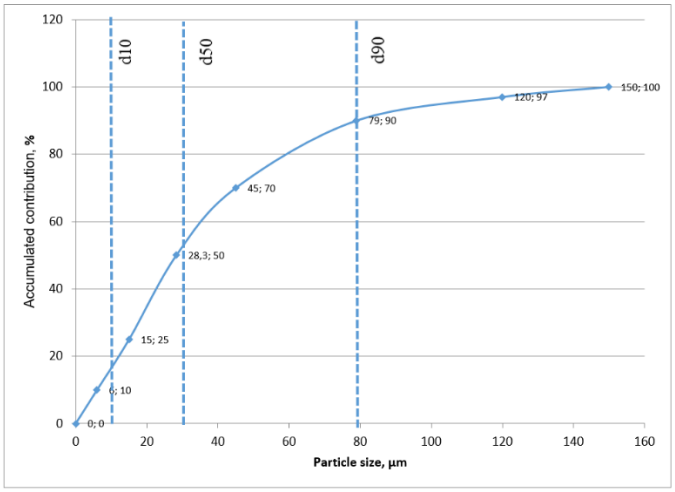


Figure 3 – Particle size distribution of Salicornia europaea powder

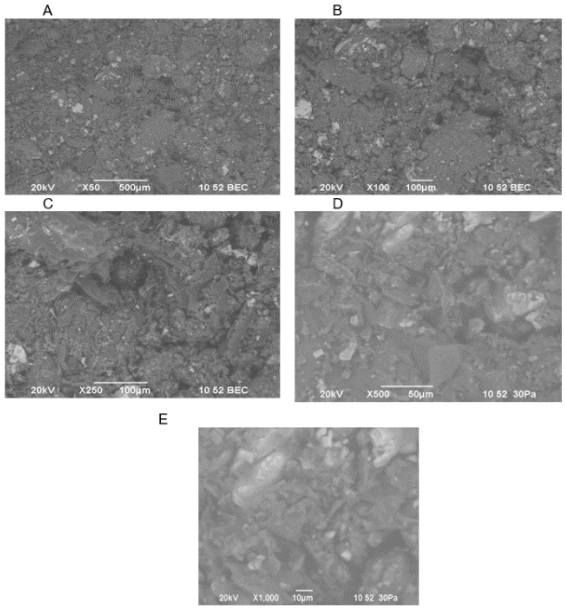


Figure 4 – Microstructure of Salicornia europaea powder at different magnification levels:
A – ×50; B – ×100; C – ×250; D – ×500; E – ×1000

In order to more deeply assess the dispersion composition, the characteristic particle sizes were determined. According to the results of granulometric analysis, the characteristic particle sizes were determined: d10 = 6 μm, d50 = 28.3 μm and d90 = 79 μm. These indicators indicate that the powder has a finely dispersed and polydisperse structure. The predominance of fine particles in the

powder contributes to an increase in its specific surface area, increased water binding capacity and uniform distribution in food systems.

As the magnification level increases (×250 and ×500), the surface structure of the powder particles becomes more clearly visible. The surface of the particles is characterized by a porous structure, which contributes to their high water absorption and retention capacity. In addition, microcracks and small cavities are observed on the surface of the particles.

At the highest magnification (×1000), the microporous structure of the powder particles is clearly visible. Such a structure indicates the high adsorption properties of the plant powder and may increase its water-binding capacity in food products. The results obtained indicate that the structural features of Salicornia europaea powder are closely related to its functional and technological properties.

Swelling capacity is one of the important indicators in food technology, because this property characterizes the ability of the ingredient to bind water. The results of the study showed that Salicornia powder can absorb water well and retain it in a certain amount. This property plays an important role in forming the structure of the product and improving its consistency. In addition, high water binding capacity contributes to improving the technological properties of the product and increasing the quality of the finished product. According to the results of the study, it was determined that the swelling coefficient of the powder is 3.2. This indicator indicates that the powder has a good water binding ability.

As a result of the research conducted in this way, the physicochemical, mineral and functional properties of Salicornia plant powder were determined, and its possibility of use as a natural salt substitute and functional ingredient in the food industry was scientifically substantiated.

The safety indicators of Salicornia europaea powder were studied. According to the results of determining the amount of toxic elements, the content of lead (Pb) was 0.0021 mg/kg, cadmium (Cd) was 0.0006 mg/kg, and arsenic and mercury were not detected. These indicators do not exceed the permissible levels established in regulatory documents (Table 3).

Table 3 – Amount of toxic elements in Salicornia europaea powder

Көрсеткіш	Norm	Result	RD for test methods
Pb, mg/kg, no more	≤0,5	0,0021 ± 0,0001	GOST 32689.1-2014
Cd, mg/kg, no more	≤0,03	0,0006 ± 0,0002	
As, mg/kg, no more	≤0,5	Not specified	
Hg, mg/kg, no more	≤0,1	Not specified	

In addition, no pesticide residues were detected in the plant powder. HCH isomers and DDT and its metabolites were not detected during the study. These results indicate that the studied plant raw materials are environmentally safe (Table 4).

Table 4 – Pesticide residues in Salicornia europaea powder

Indicator	Norm	Result	RD For test methods
ГХЦГ (α, β, γ-изомерлері)	≤0,1	Not specified	GOST 32689.1-2014
ДДТ and its metabolites	≤0,1	Not specified	

The results of microbiological analysis also showed the safety of the studied powder. The content of mesophilic aerobic and facultative anaerobic microorganisms did not exceed the permissible level. In addition, pathogenic microorganisms such as Escherichia coli, Salmonella and Staphylococcus aureus were not detected (Table 5).

Table 5 – Microbiological parameters of Salicornia europaea powder

Indicator	Norm	Result	Regulatory documents
Mold fungi, КОЕ/г	≤10^3	1,2×10^2	GOST 10444.12-2013
Yeasts, КОЕ/г	≤100	31	GOST 10444.12-2013
КМАFАnМ, КОЕ/г	≤5×10^5	3,8×10^4	GOST 10444.15-94
Escherichia coli bacteria (coliforms)	No way	Not specified	GOST 31747-2012
Pathogenic microorganisms (including Salmonella), per 25 g of product	No way	Not specified	GOST 31659-2012
Staphylococcus aureus, 1,0 г in the product	No way	Not specified	GOST 31746-2012

The results of the study are of practical importance for the development of low-salt functional products in the food industry. The study revealed that Salicornia europaea plant powder is rich in mineral elements and contains phenolic compounds and flavonoids. In addition, the porous microstructure of the powder particles and the high swelling coefficient indicate its high water-binding capacity. These properties allow the use of plant powder as a technological ingredient in food products. The results obtained indicate that Salicornia europaea powder can be used as a natural salt substitute in the production technology of low-salt meat products, including meat chips. The use of such plant-based raw materials allows to increase the nutritional and biological value of the finished product, as well as to reduce the sodium content.

Conclusion

As a result of the conducted research, the physicochemical, mineral and functional-technological properties of the powder obtained from the Salicornia europaea plant growing in the Sozak district of the Turkestan region were determined. According to the research results, the moisture content of the plant raw materials was 2.61%, and the total ash content was 15.17%. As a result of the analysis of the mineral composition, it was determined that the elements sodium (32.89%) and chlorine (33.51%) predominate, as well as the presence of magnesium, silicon, potassium and calcium. In addition, the plant powder contained phenolic compounds and flavonoids, the amount of which was 2.41% and 1.37%, respectively. The results of the sieve analysis showed that the main part of the powder particles belonged to the 0.25-0.5 mm fraction. Microstructural study revealed that the powder particles have a porous structure and show a high water binding capacity. The swelling coefficient was 3.2. In terms of safety indicators, toxic elements, pesticide residues and microbiological indicators met the regulatory requirements. The results of the conducted research have shown that Salicornia europaea plant powder is a promising raw material for use as a natural salt substitute and functional ingredient in the food industry. These results indicate the possibility of introducing Salicornia europaea powder into the technology of production of low-salt functional food products. The issue of using halophyte plants in food production in Kazakhstan has not been sufficiently studied, therefore, the study of the chemical composition and functional properties of Salicornia europaea plant is of scientific and practical importance.

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SALICORNIA EUROPAEA ӨСІМДІГІ ҰНТАҒЫНЫҢ ХИМИЯЛЫҚ ҚҰРАМЫ ЖӘНЕ ФУНКЦИОНАЛДЫ-ТЕХНОЛОГИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

Бұл зерттеудің мақсаты – Түркістан облысы, Созақ ауданы, Құмкент ауылы маңынан жиналған Salicornia europaea өсімдігінен алынған ұнтақтың физика-химиялық, минералдық және функционалды-технологиялық қасиеттерін зерттеу және оны тағам өнімдерінде табиғи тұз алмастырғыш ретінде қолдану мүмкіндігін ғылыми тұрғыдан негіздеу. Зерттеу барысында өсімдік шикізатының ылғалдылығы 2,61%, жалпы күл мөлшері 15,17% екендігі анықталды. Минералдық құрамды талдау нәтижесінде натрий (Na) – 32,89% және хлор (Cl) – 33,51% элементтерінің басым екендігі, сондай-ақ Mg, Si, K және Ca элементтерінің бар екендігі көрсетілді. Ұнтақтың биологиялық белсенді қосылыстары анықталып, жалпы фенолдар мөлшері 2,41%, флавоноидтар мөлшері 1,37% болды. Ситалық талдау нәтижелері ұнтақтың негізгі бөлігі 0,25-0,5 мм фракциясына тиесілі екенін көрсетті, ал микроструктуралық зерттеу бөлшектер бетінің кеуекті құрылымымен сипатталатынын анықтады. Ұнтақтың ісіну коэффициенті 3,2 болып, су байланыстыру қабілетінің жоғары екендігін көрсетті. Қауіпсіздік көрсеткіштері бойынша токсикалық элементтер, пестицид қалдықтары және микробиологиялық көрсеткіштер нормативтік талаптарға сәйкес келді. Зерттеудің ғылыми жаңалығы – Түркістан облысы Созақ ауданы аумағында өсетін Salicornia europaea өсімдігінен алынған ұнтақтың химиялық құрамы мен функционалды-технологиялық қасиеттерінің кешенді түрде зерттелуі және оның тағам өнеркәсібінде табиғи тұз алмастырғыш ретінде қолдану мүмкіндігінің ғылыми тұрғыдан негізделуі болып табылады. Алынған нәтижелер Salicornia europaea ұнтағының табиғи тұз алмастырғыш және функционалды ингредиент ретінде тағам өнеркәсібінде қолдануға перспективалы екенін дәлелдейді.

Түйін сөздер: *Salicornia europaea, өсімдік ұнтағы, тұз алмастырғыш, минералдық құрам, фенолдық қосылыстар, флавоноидтар, микроструктура, функционалды қасиеттер.*

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ИССЛЕДОВАНИЕ ХИМИЧЕСКОГО СОСТАВА И ФУНКЦИОНАЛЬНО-ТЕХНОЛОГИЧЕСКИХ СВОЙСТВ ПОРОШКА РАСТЕНИЯ *SALICORNIA EUROPAEA*

Целью данного исследования является изучение физико-химических, минеральных и функционально-технологических свойств порошка, полученного из растения Salicornia europaea, собранного вблизи села Кумкент Сузакского района Туркестанской области, а также научное обоснование возможности его использования в пищевых продуктах в качестве природного заменителя поваренной соли. В ходе исследования установлено, что влажность растительного сырья составила 2,61%, а общее содержание золы – 15,17%. Результаты анализа минерального состава показали преобладание натрия (Na) – 32,89% и хлора (Cl) – 33,51%, а также наличие таких элементов, как Mg, Si, K и Ca. Определено содержание биологически активных соединений: общий уровень фенольных соединений составил 2,41%, флавоноидов – 1,37%. Результаты ситового анализа показали, что основная часть порошка представлена фракцией размером 0,25-0,5 мм, а микроструктурные исследования выявили пористую структуру поверхности частиц. Коэффициент набухаемости порошка составил 3,2, что свидетельствует о высокой водосвязывающей способности. По показателям безопасности содержание токсичных элементов, остаточных количеств пестицидов и микробиологические показатели соответствуют нормативным требованиям. Научная новизна исследования заключается в том, что проведено комплексное исследование химического состава и функционально-технологических свойств порошка растения Salicornia europaea, произрастающего на территории Сузакского района Туркестанской области, а также научно обоснована возможность его использования в пищевой промышленности в качестве природного заменителя поваренной соли. Полученные результаты подтверждают перспективность использования порошка Salicornia europaea в пищевой промышленности в качестве природного заменителя соли и функционального ингредиента.

Ключевые слова: *Salicornia europaea, растительный порошок, заменитель соли, минеральный состав, фенольные соединения, флавоноиды, микроструктура, функциональные свойства.*

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