Article

Influence of Different Packages and Storage Temperatures on the Yield and Quality of Edible *Allium* Species

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Abstract: The genus *Allium* L. attracts the attention of researchers due to the presence of valuable medicinal, nutritional and decorative properties, adaptive capabilities, resistance to pests and diseases, ecological plasticity in its representatives, which contributes to the competitiveness of species and the manifestation of a high degree of adaptation outside natural areas and wide geographical distribution. *Allium* resources in Russia are a potential source of genes for expanding the genetic base of agricultural crops. The leaves of *Allium* crops have a short freshness period and quickly deteriorate due to spoilage and loss of water. The aim of the work was to establish the yield and change in the quality of green leaves of Allium species introduced into the Moscow region during short-term storage, depending on the type of packaging, storage period and temperature. 4-5-year-old plants of 4 species (*A. altyncolicum*, *A. chyatophorum*, *A. nutans* and *A. turkestanicum*) were grown on the collection plot of perennial onions of VNIIO, a branch of the FGBNU FNTSO. In the conditions of the Moscow region, the yield per leaf generation varied from 2.7 kg/m^2 (*A. altyncolicum*) to 4.9 kg/m^2 (*A. cyathophorum*). The maximum yield of marketable products was noted in hermetically sealed plastic bags when stored for 10 days at a temperature of +6 to + 8^{0}C in a refrigerator with controlled conditions: *A. turkestanicum* - 70.0%, *A. cyathophorum* - 75.5%, *A. altyncolicum* - 84.9%, *A. nutans* - 92.9%. The maximum content of vitamin C during storage in hermetically bags with a density of 100 μm was found in *A. altyncolicum* (37.1 mg per 100 g) and *A. nutans* (42 mg per 100 g). In other species, the maximum value of this indicator was noted before storage. A slight increase in the amount of sugars after storage for 10 days was noted in species with a linear leaf shape when stored in a polymer box. Temperature control is the most effective approach to extend the shelf life of fresh green leaves by measuring its weight loss and vitamin C.

Keywords: Edible *Allium*; productivity; biochemical composition; keeping quality

1. Introduction

Accelerated lifestyle, improper and malnutrition and the increase in obesity are some of the negative features of modern humanity. It is for this reason that consumers are increasingly aware of the need to consume seasonally available, new food sources characterized by a rich nutritional composition and a significant content of phytochemicals with a high antioxidant capacity [1]. In fact, numerous studies show that healthy eating and the prevention of various degenerative diseases are closely linked, and that by consuming foods rich in biologically active compounds, phytonutrients, we can have a significant positive impact on health. One of the important components of a healthy diet today is the minimal impact on the environment. This means that a healthy diet includes foods that are rich in nutrients as well as those that are less harmful to the environment, such as fruits, vegetables, and medicinal plants [2]. Therefore, when planning a healthy daily diet, it is important to include those foods that are characterized by a rich composition of specialized, environmentally friendly metabolites. One of the neglected plant species, especially in terms of nutrition, is representatives of the genus *Allium* L.

The genus *Allium* with more than 1000 species [3] naturally distributed throughout the northern hemisphere [4]. It is one of the most diverse and largest genera of monocots [5,6]. The main centers

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of biodiversity are located in the arid and subarid regions of Southwest and Central Asia, as well as in the Mediterranean region. A much smaller center is located in the western part of North America [4]. The overwhelming morphological diversity of the genus reflects a complex taxonomic structure consisting of 15 subgenera and 72 sections of three evolutionary lineages [3]. *Allium* L. resources in Russia are a potential source of genes for expanding the genetic base of agricultural crops [1].

The genus *Allium* attracts the attention of researchers due to the presence of valuable medicinal, nutritional and decorative properties, adaptive capabilities, resistance to pests and diseases, ecological plasticity in its representatives, which contributes to the competitiveness of species and the manifestation of a high degree of adaptation outside natural areas and wide geographical distribution. It is precisely because of the rich nutritional composition and the content of phytochemicals with high therapeutic potential and the range of biological activity, from antioxidant to antimicrobial, that this plant species can be considered a functional food with a high production potential for various functional foods and foods of natural origin [7,8].

As a result of changing consumer habits, the global market for minimally processed fruits and vegetables has rapidly developed in recent years [9,10]. By 2022, this market is estimated to reach $346.05 billion [11,12]. Some of the minimally processed foods on the market are mixed vegetables for salads, soups, and sandwiches [13]. *Allium* species are well known for their use in food flavorings and seasonings, and for their therapeutic role due to its antioxidant, anti-inflammatory, and hypocholesterolemic properties [14,15].

A. altyncolicum grows in the Southern Altai, narrow local endemic, mesohygrophyte. Rhizome-bulbous plant. The phenorhythmotype is a long-term vegetative, summer green with forced winter dormancy, early summer blooming. Leaves remain green until severe frost sets in [16,17].

A. chyatophorum is endemic to China. It grows in mountain meadows and on slopes at an altitude of 2700-4600 m. Leaves flat, narrow [18].

A. nutans is endemic to the steppe communities of southern Siberia, northern Kazakhstan, and the southern Urals. Grows on rocky steppe and meadow slopes, on bedrock outcrops [19].

In nature, the range of *A. turkestanicum* covers Central Asia from the Aral Sea to Balkhash and the Tien Shan. Endemic. Grows on outcrops of variegated rocks [20].

Fresh vegetables are metabolically active for long period after harvesting due to both endogenous activity, such as respiration, and external factors such as physical injury, microbial flora, water loss and storage temperature. Green onions deteriorate quickly and have a short sales period in the distribution network. Freshly cut green onion leaves stored at 0°C can be stored for up to 4 weeks. Currently, green onions are stored in supermarkets and chains, as a rule, at a temperature of +6 to +8^{0}C and above. Moisture loss or transpiration is an important physiological process that affects the main qualities of fresh vegetables such as saleable weight, appearance, texture and flavour. A loss in weight of only 5 % often causes fresh produce to lose freshness and appear wilted. To preserve the quality and extend the shelf life of herbs, it is necessary, first of all, to reduce water losses. This can be achieved using various types of packaging, including a plastic bag.

Allium leaves are highly perishable products that quickly lose their marketability mainly due to high metabolic rate, water content, weight loss, softening, discoloration, microbial and enzymatic spoilage, combined with poor management and transportation to the consumer. Important indicators of the quality of green onions are freshness, the absence of mechanical damage and decay, an even and healthy minimum cut [21]. An alternative storage method is needed to extend the shelf life of the leaves.

The purpose of the study is to determine the yield and study the changes in the quality of green leaves of *Allium* L. species introduced into the Moscow region during short-term storage, depending on the type of packaging, duration and temperature of storage.

2. Materials and Methods

In connection with the study and maintenance of germ plasm, the Allium collection was created at VNIIO, a branch of the Federal State Budget Scientific Institution of the Federal Scientific and

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Practical Center for Ecology from 12 subgenera, 34 sections, 80 species *ex situ*: a) seeds; b) field "live" collections.

The list of studied Allium species of the food direction is presented according to the standards adopted in the International Plant Names Index (IPNI) or The Plant List database (Table 1, Fig. 1). In the Russian Federation, the commercial varieties *A. altyncolicum* and *A. nutans* are cultivated in the fields, while *A. chyatophorum* and *A. turkestanicum* are cultivated in gardens by the population.

Table 1. Complex of species of the genus Allium L. of the food direction.

Subgenus	Section	Species	Leaf shape
Cepa	*Schoenoprasum* Dum.	*A. altyncolicum* N. Friesen	fistulate
Cyathophora	*Cyathophora* R.M. Fritsch	*A. chyatophorum* Bureau & Franch	linear
Rhizirideum	*Rhizirideum* G. Don ex Koch	*A. nutans* L.	
Allium	*Mediasia* F.O.Khass., Yengalycheva & N. Friesen	*A. turkestanicum* Regel	

A) *A. altyncolicum* B) *A. chyatophorum*

C) *A. nutans* D) *A. turkestanicum*

Figure 1. Studied species of *Allium* for food purposes.

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Research methods - introduction, mobilization of existing plant genetic resources. Preservation and maintenance of the genetic collection of representatives of the genus *Allium* L. was carried out as part of the implementation of the State task.

Plants were grown on the collection plot of perennial onions, VNIIO, a branch of the Federal State Budget Scientific Institution of the Federal Scientific and Practical Center for Natural Resources (Moscow region, N 55º36' E 38°1'). The sown area of each species was 20 m². The soil of the experimental plot is alluvial meadow, has a high level of natural fertility.

The selection of standard products for storage was carried out in accordance with the requirements of the Interstate Standard GOST 34214-2017 "Fresh green onions. Specifications". Leaf samples were taken in the morning hours in the phase of mass growth of plants in adult generative individuals, growing for 3 years under the conditions of introduction. Fresh green onion leaves were packed in plastic bags with a density of 100 μm, size 35 × 50 cm, weight 900 g. Samples placed in an open polymer box lined with polyethylene bag served as controls. After cutting, the leaves were stored in an adjustable refrigerating chamber for 5 days and for 10 days at a temperature of +6 to +8⁰C. Two variants of leaf storage were studied: an open polymer box lined with polyethylene bag and a hermetically plastic bag with a density of 100 μm.

The samples were weighed on the day of the experiment, on the 5th and 10th days for data collection. The experiment was based on a single-factor completely randomized experiment with three repetitions. Storage was carried out for 5 days at a temperature of +10 to +12⁰C, 10 days at a temperature of +6 to +8⁰C in a refrigerator with controlled storage conditions. Relative air humidity 90±3%. Relative humidity and temperature were controlled with a DT-171 temperature and humidity recorder (China). A comparative evaluation of products was carried out in terms of natural weight loss, separation of absolute waste and changes in the chemical composition. Yellowed or rotted leaves were separated and weighed. The determination of the mass fraction of green onions that do not meet the quality requirements was calculated according to GOST 34214-2017 "Fresh green onions. Specifications".

Biochemical analyzes were carried out before and after the expiration of the shelf life: dry matter - thermostatic-weight method (drying at 105°C); sugars - according to Bertrand; vitamin C - according to Murri; nitrates - ionometrically according to the TsINAO method [22].

The data obtained were analyzed for statistical significance using the Microsoft Excel 2007 program. For each type of onion, the arithmetic mean values of the studied parameters and the standard deviation of the sample from the mean were calculated [23].

3. Results and discussion

Under the conditions of the introduction of the Moscow region, the maximum leaf yield was recorded in *A. cyathophorum* - 4.9 kg/m² per leaf generation. The increase in yield is due to high productivity (1.2 kg/plant) and a large number of leaves (469 pieces). The leaves are flat, 43.3 cm long and 1.2 cm wide (Table 2). In *A. nutans* variety Broad-leaved, the productivity per leaf generation was 0.98 kg, while the yield was fixed at 3.9 kg/m². The increase in yield is associated with a large number of leaves (240 pieces/plant) and leaf width (1.5 cm). The productivity of *A. turkestanicum* was noted at the level of 0.8 kg/plant, the yield was 3.2 kg/m². In *A. altyncolicum*, the productivity was 0.7 kg/plant, the yield was 2.7 kg/m².

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Table 2. The structure of the crop of perennial food onions (plants 3 years old) in the phase of consumer ripeness in the conditions of the Moscow region.

Indicators	*A. nutans*	*A. cyathophorum*	*A. altyncolicum*	*A. turkestanicum*	LSD_{05}
Plant height before cutting, cm	40,0	50,6	74,6	37,4	-
Number of monocarpic shoots, pieces/plant	30	67	95	36	-
Number of leaves, pcs.	240	469	285	180	-
Sheet length, cm	32,4	43,3	52,0	36,5	-
Sheet width, cm	1,5	1,2	0,5	1,3	-
Productivity, g/plant	983	1235	668	820	197
Yield, kg/m^2	3,9	4,9	2,7	3,2	0,9

Source: [Compiled by the authors].

Of the packaging methods we studied, the maximum yield of *Allium* after storage was in hermetically bags, since there was practically no natural weight loss in them. In the bag-lined polymer box, the natural weight loss was high (Table 3). The shelf life of Allium leaves at ambient temperature is 24 hours.

In hermetically plastic bags with a density of 100 microns, moisture condensation was noted during storage of products. The reason is that the high air humidity and low O_2 levels inside the plastic bags have led to the accumulation of moisture, a by-product of respiration, resulting in condensation, which provides a favorable environment for the growth of rot-causing microorganisms.

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Table 3. Preservation of green leaves of representatives of the genus *Allium*, depending on the different packages and storage temperature.

Temperature, shelf life	Species	Type of packaging	Marketable output, %	Losses, %	
				weight loss, %	absolute waste, %
+10 to +12⁰C, 5 days	*A. nutans*	Polymer box lined with plastic bag	73,1	11,5	15,4
		Hermetic plastic bag	84,2	0,0	15,8
	A. cyathophorum	Polymer box lined with plastic bag	69,6	10,3	20,1
		Hermetic plastic bag	80,4	0,0	19,6
	A. altyncolicum	Polymer box lined with plastic bag	65,8	11,8	22,4
		Hermetic plastic bag	70,6	0,0	29,4
	A. turkestanicum	Polymer box lined with plastic bag	59,7	11,5	28,8
		Hermetic plastic bag	69,1	0,0	30,9
	Mean	Polymer box lined with plastic bag	67,1	11,3	21,7
		Hermetic plastic bag	76,1	0,0	23,9
LSD_{05}		-	2,9	-	-
+6 to +8⁰C, 10 days	*A. nutans*	Polymer box lined with plastic bag	83,2	9,3	7,5
		Hermetic plastic bag	92,9	0,0	7,1
	A. cyathophorum	Polymer box lined with plastic bag	65,2	8,9	25,9
		Hermetic plastic bag	75,5	0,0	24,5
	A. altyncolicum	Polymer box lined with plastic bag	72,0	10,2	17,8
		Hermetic plastic bag	84,9	0,0	15,1
	A. turkestanicum	Polymer box lined with plastic bag	70,0	10,4	19,6
		Hermetic plastic bag	79,3	0,0	20,7
	Mean	Polymer box lined with plastic bag	72,6	9,7	17,7
		Hermetic plastic bag	83,2	0,0	16,9
LSD_{05}		-	3,1	-	-

Source: [Compiled by the authors].

Higher temperatures significantly increase decay and loss of turgor, shorten the period of implementation. Thus, the storage temperature regime of +10 to +12⁰C for 5 days was on average worse in all respects compared to the temperature regime of +6 to +8⁰C for 10 days.

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A. altyncolicum had the most dry substances (14.3%), mono- (2.92%), di- (2.11%) and total (5.035%) sugars in freshly cut leaves, and vitamin C - in *A nutans* (37.6 mg%) (Table 4). This indicates a high biological value of these samples for rational human nutrition.

After storage, biochemical analysis of green onion leaves was carried out on the best storage option (10 days at a temperature of +6 to +8^{0}C) (Table 4). The content of quality indicators of green leaves of *Allium* representatives after storage was calculated taking into account the weight loss of products.

Table 4. Biochemical composition of green leaves of *Allium* representatives, depending on the types of packaging, before and after storage for 10 days in a refrigerator at a temperature of +6 to + 8^{0}C.

Species	Type of packaging	Dry matter, %	Vitamin C, mg per 100 g	Sugar, %			Nitrates, mg/kg
				mono-	di-	total	
A. nutans	Before storage	11,0	37,6	2,42	0,66	3,08	88
	Polymer box lined with plastic bag	12,5	35,3	3,61	1,42	5,03	77
	Hermetic plastic bag	11,0	42,0	2,57	0,91	3,48	92
A. cyathophorum	Before storage	9,9	30,8	2,29	1,37	3,65	88
	Polymer box lined with plastic bag	10,1	20,2	4,47	0,47	4,94	86
	Hermetic plastic bag	9,4	21,3	2,62	0,07	2,69	91
A. altyncolicum	Before storage	14,3	34,7	2,92	2,11	5,03	89
	Polymer box lined with plastic bag	15,5	16,5	2,37	1,57	3,99	78
	Hermetic plastic bag	15,1	37,1	2,95	1,96	4,91	92
A. turkestanicum	Before storage	11,2	35,0	2,13	1,52	3,65	92
	Polymer box lined with plastic bag	12,4	15,7	3,93	0,65	4,58	78
	Hermetic plastic bag	11,2	25,6	3,04	0,33	3,37	91
Mean	Before storage	11,6	34,5	2,44	1,42	3,85	89
	Polymer box lined with plastic bag	12,6	21,9	3,60	1,03	4,64	80
	Hermetic plastic bag	11,7	31,5	2,80	0,82	3,61	92
Standard deviation		2,04	9,05	0,72	0,66	0,83	5,84

Source: [Compiled by the authors].

An increase in the content of vitamin C during storage in hermetically bags was found in *A. altyncolicum* (37.1 mg per 100 g) and *A. nutans* (42.0 mg per 100 g). In other species, the maximum value of this indicator was noted before storage. The same phenomenon was noted during the storage of vegetable coriander greens in plastic bags [24].

In species with a linear leaf shape, when stored for 10 days in a polymer box, there was a tendency to increase the amount of sugars after storage, but a slight decrease in this indicator was recorded in *A. altyncolicum* with horn-shaped leaves compared to the data before storage.

A slight increase in the content of nitrates in the leaves by 3-4 mg/kg was established when stored in a hermetically plastic bag, and when stored in a polymer box lined with plastic bag, the content of nitrates decreased by an average of 9 mg/kg.

4. Conclusions

Nowadays, consumers are looking for products with a beneficial effect, because they are more concerned about their health and well-being. Generally, in our studies, 3-year-old *A. altyncolicum* plants formed a yield of 2.7 kg/m^2, *A. chyatophorum* - 4.9 kg/m^2, *A. nutans* - 3.9 kg/m^2, *A. turkestanicum* - 3.2 kg/m^2. The maximum content of vitamin C during storage in hermetically bags with a density of 100 μm was found in *A. altyncolicum* (37.1 mg per 100 g) and *A. nutans* (42 mg per 100 g). In other species, the maximum value of this indicator was noted before storage. An increase in the amount of sugars after storage for 10 days was noted in species with a linear leaf shape when stored in an open polymer box. *Allium* leaves can be considered a valuable source of many specialized metabolites with high antioxidant capacity and thus have a high production potential for a variety of naturally occurring functional foods and nutritional supplements that are important for promoting human health. Good packaging can prevent physical leaf damage and chemical contamination. Careful handling of vegetables during loading and unloading can reduce mechanical damage, and proper packaging, neither too tight nor too loose, affects the market value of the product. Future research should focus on exploring new types of packaging and other types of edible *Allium*.

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