Journal of
Agriculture and Biology
ISSN: 3007-1755 (Print), 3007-1763 (Online)

Research Article

Accelerated Fruiting of Sea Buckthorn (*Hippophae rhamnoides* L.) Meadow-Gardens in Southeast Kazakhstan

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ABSTRACT

This work is novel because it demonstrates that high-density meadow-garden technology enables commercial fruiting of sea buckthorn (*Hippophae rhamnoides* L.) as early as the second year- a major advancement over traditional systems. The accelerated establishment and productivity of sea buckthorn in meadow-garden systems represent an important direction for enhancing the economic sustainability of fruit production in harsh continental climates. This study assessed the productivity potential of a two year old sea buckthorn meadow garden established under the sharp continental conditions of the Semirechye farm, Almaty region, Kazakhstan. Seven varieties developed by the M.A. Lisavenko Siberian Research Institute of Horticulture were evaluated at a planting density of 40,000 plants/ha. Only two varieties (Augustine and Inia) entered the stage of commercial fruiting by the second year. The variety Augustine demonstrated the highest productivity, yielding 25 t/ha, whereas Inia produced 13 t/ha. In addition to yield, Augustine was characterized by superior fruit size (1.15 g/berry), which was twice that of the control variety Elizaveta and 1.78 times greater than Inia. These results highlight the clear advantage of Augustine for early-fruiting meadow-gardens in Kazakhstan. Economic analysis showed that cultivation of Augustine enables near-complete recovery of investment and operational costs by the second year, despite reliance on labor-intensive manual harvesting. Furthermore, profitability is expected to increase substantially in the third year with the planned application of technological innovations, including complete above-ground cutting of shrubs, shock freezing, and mechanized fruit detachment. The findings highlight Augustine as the most promising cultivar for early commercial returns under Kazakhstan's sharp continental climate.

Keywords: Sea buckthorn, Meadow garden, Industry, Kazakhstan.

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Article History
Received: July 15, 2025
Accepted: November 03, 2025
Published: November 20, 2025

INTRODUCTION

Sea buckthorn (*Hippophae rhamnoides* L.) is an important deciduous shrub of the genus *Hippophae* in the family *Elaeagnaceae*. Its species are naturally distributed in the Eurasian region, starting from China, Russia, Kazakhstan & Hindu-Kush Himalaya (Indo-Pak regions). The second band of distribution continues from France, Southern England, extending to Lithuania, Estonia, Norway, and Finland (Nybom *et al.,* 2023; Letchamo *et al.,* 2018). It is an important economic plant that contains almost 200 bioactive compounds used in Food, Nutrition and medicine industry (Wang *et al.,* 2022). Its fruit (berries) were used long ago (1300 years) for medicinal purposes in Central Asia, China, Mongolia and the Tibetan regions (Musayev, 2013). Most recently Sea buckthorn has gained enormous importance for making the anti-cancerous drugs, beauty products and nutritional supplements.

Due to its importance, it is commonly termed as 'Golden bush', Gold mine' and 'wonder plant (Dubey, 2024; Stobdan, 2013). Kazakhstan is an important habitat for sea buckthorn. The short growing season and extremely low winter temperatures in the northern, central and eastern regions do not affect its distribution across the republic (Ghundov-Mosanu, 2020). In the southeast, in the Almaty and Zhetysu regions, foothill areas with a milder climate are suitable for it. It has better adopted the altitudes in the range of 850-1300 m above sea level and the sum of active temperatures not exceeding 33˚C. Too hot, and higher solar insolation of the winter period reduces the winter hardiness of generative buds of plants and, as a consequence, their productivity. Traditional technologies for growing sea buckthorn in Kazakhstan provide the placement of 1-2 thousand plants per/ha that begin to bear fruit commercially in the 5th year after planting. At the same time, their productivity, depending on the variety, does not exceed 13 t / ha with a placement scheme of 3.5 x 1 m (2850 plants / ha). The productivity of varieties with smaller berries decreased almost proportionally depending on their average weight (Oleychenko, 1993).

The projected production of one thousand tons of fruit by 2030 is possible only with the mass introduction of the technology of growing sea buckthorn according to the meadow-garden type developed in Kazakhstan (Oleychenko, 2001). Meadow garden technology has been a progressive technique in horticulture crops for optimized yields. Its difference from other technologies is the super-thickened planting of 40 thousand plants/ha. This scheme almost eliminates the manual labor costs for plantation care due to continuous mulching of the soil with film, the use of drip irrigation and foliar feeding & protection from pests and diseases using surface spraying. The sea buckthorn meadow-garden technology has been implemented since 2018 in Kyrgyzstan, in the Okenov farm (Issyk-Kul region), and continued in Kazakhstan, in the Pitomnik-Semirechye farm (Almaty region), where in 2022 a 0.5 ha plot was planted using this technology. In the Okenov farm, a yield of about 40 t/ha was obtained in the 3rd year after planting, and in the Pitomnik-Semirechye farm, commercial fruiting was noted for individual varieties already in the second year (Oleichenko, 2023). Keeping in view the importance of this production system, present study was planned to assess a set of biometric observations of plants to evaluate this production system.

Unlike traditional sea buckthorn orchards in Kazakhstan that fruit in the 5th year with 1,000–2,850 plants/ha, the meadow-garden technology tested here (40,000 plants/ha) provides an accelerated production model capable of yielding commercially in only two years. This represents a major improvement for growers operating under harsh continental climates.

MATERIALS AND METHODS

The experiment was laid down on promising varieties of sea buckthorn, grown using meadow-garden technology in 2022-2023 in Semirechye nursery, Enbekshikazakh district, Almaty region. The site is located in the arid foothill zone at an altitude of 840 m above sea level and is characterized by a sharp continental climate. The average annual air temperature was 8.7°C. The transition of mean daily temperatures above 10°C occurred on April 13th in spring and during the second ten-day period of October in autumn.

The number of days with temperatures above 10°C was 182 days, the sum of average daily temperatures above 10°C was about 3400°C. The study area receives an average annual precipitation of 440 mm, distributed as 15.6% in winter, 20.8% in summer, and 21.4% in autumn. The transition of air temperatures from positive to negative values typically occurs in the first decade of November. Stable snow cover usually forms between late November and early December, persisting for 85–100 days; however, it is uneven, and frequent thaws may result in complete melting. The absolute minimum air temperature recorded in the region is –38 °C. Summer is the longest season, lasting 120–182 days, with the hot period extending until the second decade of October. Daily temperature amplitudes are relatively high, averaging 12 °C between day and night. Summer relative humidity is low, fluctuating between 44% and 33%.

Table 1. Content of humus, CO_2, carbonates, and mobile forms of nutrients in dark chestnut soil.

Depth (cm)	Humus (%)	CO_2 (%)	pH	Mobil forms mg/kg		
				N hidrolyzable	P_2O_5	K_2O
0-25	2.68	5.92	7.2	64.1	39.0	880
25-50	2.60	6.01	7.4	62.4	36.1	860
50-75	2.07	6.76	7.6	54.8	28.4	696
75-100	1.34	7.59	7.7	49.2	15.1	544

The autumn transition of mean daily temperatures below 10 °C generally begins in the third decade of September to early October and lasts for 30–50 days. During the winter of 2022–2023, conditions were moderately cold, with minimum temperatures reaching –28 °C in January, while no spring frosts were observed. The experimental site soils are classified as dark chestnut, which are well suited for fruit and berry cultivation, including sea buckthorn (Table 1).

Experimental Design

A field experiment was established in 2022 to evaluate the productivity and agro-economic efficiency of meadow-garden technology for sea buckthorn (*Hippophae rhamnoides* L.). Seven varieties developed at the M.A. Lisavenko Siberian Research Institute of Horticulture were tested: 1) Elizabet (control), 2) Altayskaya, 3) Augustine, 4) Zlata, 5) Inia, 6) Klavdia, and 7) Etna. The trial was arranged in a randomized design with three replications, each consisting of 10 plants.

Planting Scheme

Seedlings were planted at a spacing of 80 × 30 cm, corresponding to a density of 40,000 plants per hectare. To ensure effective pollination, 6% of the total plantation was allocated to male plants.

Agro-Economic Assessment

In addition to evaluating varietal performance, a comparative agro-economic assessment of three sea buckthorn cultivation technologies was conducted to determine the efficiency and profitability of meadow-garden management practices.

Data Collection

Phenological and biometric measurements of plant growth, development and fruiting were performed according to the guidelines of methodological standards of the Uman Agricultural Institute Records, Observations, Analyses, Data Processing in Experiments with Fruit and Berry Crops. Moreover, the study was conducted with the help of the program-methodological scheme of varietal studies of fruit, berry and nut crops, which was worked out at the I.V. Michurin All-Russian Research Institute of Horticulture (Lobanov, 1973).

Phenological Observations

The phase of budding, the beginning of shoot growth, the beginning and mass ripening and the end of vegetation were taken into account.

Biometric observations

Biometric parameters were measured

Productive Branching and Biomass

The counts of productive branches, the raw and dry mass (g) of wood and leaves of all 10 plants in each replica were measured. The weight after oven-drying of the samples in thermostats was recorded as dry weight.

Leaf Area

100 leaves per replicate were taken and used to calculate the mean leaf area (mm^2) and measured on a millimeter palette.

Leaf Number

The number of leaves were estimated by counting the number of all leaves on one of the visually average plants in each replicate and then extrapolated to the replicate level.

Fruit yield

The total fruit mass (g) was counted and the number of fruits counted on all 10 plants per replicate. Mean fruit weight was determined based on a representative of 100 fruit weight on the weight scales.

Biochemical Analysis

Biochemical analyses of sea buckthorn fruits were conducted at the Mass Analysis Laboratory of Kazakh National Agrarian Research University. Samples of 1 kg were collected as composite samples uniformly selected from each replicate. Dry matter content (%) was determined using a refractometer. Vitamin C content was assessed according to the method of Mori *et al.,* (1998) and Raman *et al.,* (2022). Total sugars were determined using Bertrand's method (1906), while pectin content was estimated gravimetrically (Begum *et al.,* 2014; Carré & Haynes, 1922). Total acidity was measured following Ermakov (Karnjanawipagul *et al.,* 2010), and carotene content was determined spectrophotometrically (Patil *et al.*, 2010).

Economic Assessment

An economic assessment of the meadow-garden technology was performed to evaluate the prospects for sea buckthorn cultivation in Kazakhstan based on standard agro-economic criteria.

Experimental Plot Establishment

The experimental plot was established between April 12–14, 2022, using seedlings imported from Barnaul and stored under refrigerated conditions at near 100% humidity prior to planting. The site was ploughed to a depth of 45 cm in the previous autumn and cultivated with a chisel to 35 cm in spring. Furrows were 15 cm deep and spaced 80 cm apart, and seedlings were planted at 30 cm intervals. Prior to planting, roots were dipped in a clay slurry prepared with 30 g of Zeba aquagel, a solution containing the fungicide Topsin (1.2 g/L), and the humic-folic preparation Humic (4 g/L). This treatment significantly improved seedling survival.

Irrigation and Fertilization

A drip irrigation system (16 mm diameter, 1 L/h drippers spaced at 50 cm) delivered 25 m³/ha per hour at planting. Post-planting irrigation applied 40 m³/ha and subsequent watering was applied when soil moisture dropped below 85% of field capacity. After 2–3 years, daily irrigation was maintained at 10–20 m³/ha. The nutrient regime included foliar feeding and fertigation.

Spring Application: Humic @ 4 L/ha and soluble NPK fertilizer (14+65+ME) @ 40 kg/ha.

Summer Application: Three treatments of complex fertilizer (15+5+35+ME) @ 30 kg/ha.

Late August: P_2O_5 + K_2O fertilizer (40+60) @ 25 kg/ha.

Foliar treatments included chitosan-based Softgard + Alga600, Aminopull Forte, and microelements (Zn, B, Si) to enhance winter hardiness. Innovative cobalt fertilizer was applied to stimulate beneficial root-zone microorganisms.

Pest and Disease Management

Disease and pest control included three fungicide treatments that were used against *Endomycosis* and wilt by *fusarium*. Two acaricide treatments were applied against mites and two for sea buckthorn fly. Foliar nutrition was combined with pest management.

Harvesting

Fruits were harvested by cutting fruiting branches 10 cm above soil level, followed by stationary fruit separation.

Phenological Observations

Sea buckthorn exhibited an early onset of vegetation relative to other fruit crops. On average, 26 days elapsed from the start of vegetation to flowering, followed by 60 days until fruit ripening. Among male forms, Gnome initiated growth earliest, while the control variety Elizaveta was the latest. Flowering of female varieties lasted approximately seven days, and that of males lasted for approximately ten days, ensuring effective pollination. The total vegetation period lasted 187 days, concluding with heavy frost and leaf fall on October 10th.

RESULTS

Phenological Phases of Development of Sea Buckthorn Varieties

Phenological observations indicated that sea buckthorn varieties differ in the timing and duration of key developmental stages. The male variety Gnome exhibited the earliest onset of vegetation and flowering, with a sufficiently long flowering period, which is advantageous for pollination of fruit-bearing female plants.

Table 2. Phenological phases of development of sea buckthorn varieties

Varieties	Beginning of vegetation	Beginning of flowering	Beginning of ripening	End of vegetation
Elizabet (K)	3.04	10.04	21.08	10.10
Altayskaya	3.04	10.04	23.07	10.10
Augustine	3.04	11.04	23.07	10.10
Zlata	3.04	10.04	21.07	10.10
Inia	3.04	11.04	23.07	10.10
Klavdia	4.04	10.04	23.07	10.10
Etna	3.04	11.04	23.07	10.10
Gnom (M)	2.04	8.04	-	10.10

Flowering of Gnome began 2–3 days earlier, or coincided with, the onset of flowering in female varieties such as Augustine and Inia. Its average flowering duration of approximately 10 days provided ample overlap, ensuring effective and high-quality pollination of female flowers (Table 2).

Vegetative Development of Sea Buckthorn Varieties

In the study year, fruit ripening occurred in the third decade of July. In hot climates, ripening times of Altai varieties typically showed a little variation, a pattern confirmed by our observations. Notably, these Altai varieties differ markedly from local ecotypes. In local, wild forms of the subspecies *turkestanica*, fruit ripening usually commences in the second half of September and proceeds until the onset of low temperatures that become persistent. However, by contrast, Altai cultivars, with genetic input of other subspecies, mature in late July-early August. Fruits stay in the branches that remained physiologically fit for more than one month, then they started to desiccate and lose their marketability. This difference is critical for establishing physiologically justified harvesting dates in commercial plantations. Altai sea buckthorn also exhibits an early end to the growing season, accelerated by autumn frosts; leaf fall was observed following the onset of cold weather on October 10 and lasted 7–10 days.

Vegetative development at two years of age showed sufficient bush growth, with heights ranging from 81 cm (Zlata) to 137 cm (Etna) (Table 3). Each bush developed 3–5 large branches with 143–173 increments. By fruit maturity, the increments included small partially dried shoots (3–6 cm) and larger leafy ones. Average increment length ranged from 7.3 cm (Inia) to 9.3 cm (Altai), not exceeding 10 cm. Total growth was lowest in Inia and Zlata, 1.24 times below the control variety and 29.4% lower than the most vigorous Etna. Shoot water content varied slightly (4.2%), lowest in Elizaveta and highest in Zlata. Raw wood weight did not directly correlate with growth; the highest was recorded in Etna and the lowest in Inia, differing by 20%.

Table 3. Vegetative development of sea buckthorn varieties in a meadow garden (Avg. per 1 bush)

Varieties	Height (cm)	Number of shoots pcs	Average shoot length cm	Σ- shoot length cm	Wood mass (g)		Water content of shoots %
					Row	Dry	
Elizabet (K)	1075	332	3569	0.13	139.8	54.7	60.9
Altayskaya	1025	377	3864	0.14	143.5	55.0	61.7
Augustine	868	422	3663	0.17	147.6	55.6	62.3
Zlata	989	345	3412	0.14	138.5	51.1	63.1
Inia	843	405	3414	0.16	134.8	49.3	62.4
Klavdia	1193	325	3877	0.13	155.1	59.7	61.5
Etna	1149	330	3792	0.14	160.8	59.8	62.8
P value	<5	-	-	<5	<5	<5	-

Leaf surface of Sea Buckthorn Varieties

Naturally, due to minor differences in wood moisture content among the studied varieties, their dry wood mass ratios were generally similar. However, varieties exhibiting extreme values showed an increase of up to 3%, reaching 28%.

Table 4. Development of the leaf surface of sea buckthorn varieties

Varieties	Number of leave pcs	S- one leaf mm^2	S- one plant cm^2	Weight of one leaf (g)	Raw weight of leaves g/plant	Dry weight of leaves g/bush	Hydration of leaves%
Elizabet (K)	1075	332	3569	0.13	139.8	54.7	60.9
Altayskaya	1025	377	3864	0.14	143.5	55.0	61.7
Augustine	868	422	3663	0.17	147.6	55.6	62.3
Zlata	989	345	3412	0.14	138.5	51.1	63.1
Inia	843	405	3414	0.16	134.8	49.3	62.4
Klavdia	1193	325	3877	0.13	155.1	59.7	61.5
Etna	1149	330	3792	0.14	160.8	59.8	62.8
P value	-	<5	-	<5	<5	<5	-

Among the varieties with substantial wood accumulation, Klavdiya ranked highest, while Zlata exhibited the lowest. The remaining varieties, including the control (Elizaveta), displayed intermediate values.

Plant growth intensity was largely determined by the development of the photosynthetically active component, namely the leaf apparatus (Table 4), mirroring trends observed in wood formation. The greatest leaf numbers were recorded in Klavdiya and Etna, averaging 10.3% more than the control variety (Elizaveta) and Altayskaya, and 26.9% higher than in the weaker varieties Inia and Augustine. Interestingly, in terms of leaf morphology and size, varieties with fewer leaves had an advantage that their leaves were 29% larger than those of Elizaveta, Klavdiya, and Etna, which were practically equal in this trait.

Productivity of Sea Buckthorn Varieties

The leaf area of one plant is a derivative indicator of their number and the size of the leaf blade. Since the leaf blades of the Augustina and Inya varieties with less foliage were significantly larger than those of the other varieties that did not differ significantly in this indicator, the total area of the leaf apparatus of the plants was also leveled out. The differences between the varieties with the smallest leaf apparatus area (Inya and Zlata) and the largest (Altai and Klavdiya) were only 13.6%. Since the differences in leaf water content did not exceed 3.6%, the differences in the weight of one leaf between the varieties had approximately the same pattern. The varieties with the lowest raw leaf weight included Inya, Zlata and the control variety Elizaveta, which on average were inferior to the Etna variety, which stood out in this indicator, by 16.8%. The varieties with the lowest dry weight of leaves include only two varieties, Inya and Zlata, since the variety Elizaveta was closer to the middle group due to its greater foliage. The superiority of the varieties Etna and Klavdiya, which stood out for this indicator, was on average 16.3%. The productivity of plants was measured using two parameters which include the number of fruits on the plant and the average weight of the fruits. The largest fruit crop was observed in the new generation cultivars Augustina and Inya, which had close values for this indicator. On average, they exceeded the control variety Elizaveta by an order of magnitude. The control variety and all the other ones studied did not begin to bear fruit in the second year after planting and formed an insignificant number of fruits. The lowest indicator was shown by the variety Etna, which had 27.1% less fruit than the control variety (Table 5). The remaining varieties formed about the same number of fruits as the Control variety. The Augustina variety stood out for its large fruit size, with an average weight of fruit being more than 1 g, which is considered a high varietal trait. They exceeded this indicator for the control variety by 2 times. The other varieties also did not differ in significant fruit size and differed only slightly from the control variety. The Etna and Klavdiya varieties exceeded the control by 24%, and the Inya variety by 12%.

Table 5. Productivity of sea buckthorn varieties in a meadow garden in the second year after planting

Varieties	**Number of fruits pcs. /plant.**	**Average Weight fruit (g)**	**Productivity**	
			g/plant	**t/ha**
Elizabet (K)	56	0.58	32.5	1.22
Altayskaya	56.8	0.56	31.8	1.2
Augustine	578.6	1.15	665.4	25
Zlata	-	-	-	-
Inia	548.2	0,.65	356.3	13.4
Klavdia	40.8	0.71	29	1.09
Etna	65.6	0.73	47.9	1.8
P value	<5	<5	<5	<5

The Tree to Plant Productivity

As noted earlier, only two of the studied varieties, Augustina and Inya, entered commercial fruiting. Moreover, due to the large fruits, Augustina had an advantage of 86.8%. The other varieties were only slightly inferior to the control. Their productivity per hectare varied from 1.09 t/ha for the Altayskaya variety to 1.8 t/ha for the Etna variety. The Augustina variety, which stood out in productivity, surpassed the control variety Elizaveta by 20 times.

For sea buckthorn grown in almost continuous plantings, a differentiated study of the obtained biological mass is important. An increase in the specific gravity of fruits in relation to the leaf apparatus and wood can indicate the intensity of the variety and predict the harvesting process. The main interest here is the indicators of two varieties (Augustina and Inya) stood out in productivity, since for other varieties without fruiting, they will not have real values. The mass of wood in particular in the highly productive variety Augustina was 2.68 times less than the mass of fruits (Table 6). In the variety Inya, this ratio is 1.6 times less. Due to the higher water content of fruits, for 1 g of dry mass of wood in the variety Augustina there are only 0.42 g of fruits. In the variety Inya, this indicator is correspondingly 1.5 times less. The mass of the leaf apparatus was less than the wood and was 4.5 times less in the raw mass of fruits in the variety Augustina, and 2.6 times less in the variety Inya. In dry masses, the Augustinas corresponded to each other. For 1 g of dry mass of leaves, there were 0.637 g of fruits. The total ratio of fruits to the mass of leaves and wood in the variety Augustina was 1.7 times, and in the variety Inya it was proportional. Only Augustine and Inia produced commercial-level fruit in the second year. Thus, productivity comparisons are limited to these two genotypes at this stage; other varieties will require additional years for accurate evaluation.

Table 6. Ratio of individual parts of the tree to plant productivity

Varieties	Productivity g/plant		Fruit weight/Wood weight		Fruit weight/Leaf weight		Mass of fruits/Leaf surface area g/m²	S leaves/per 1 fruit Cm²	Number of leaves per 1 fruit pieces
	Raw	Dry	Raw	Dry	Raw	Dry			
Elizabet (K)	31.8	2.8	0.14	0.020	0.23	0.060	82.4	68	18
Altayskaya	31.8	2.9	0.13	0.021	0.22	0.052	82.3	68	18
Augustine	665.4	55.9	2.68	0.42	4.51	1.005	1816.5	6.3	1.5
Zlata	-	-	-	-	-	-	-	-	-
Inia	356.3	31.4	1.65	0.28	2.64	0.637	1043.6	6.2	1.5
Klavdia	29	2.5	0.11	0.017	0.19	0.042	74.8	95	29.2
Etna	47.9	4	0.18	0.027	0.3	0.067	126.3	57.8	17.5

Leaf Index of the Studied Sea Buckthorn Varieties

The photosynthetic potential of sea buckthorn is also reflected in fruit yield per unit leaf area. In intensive plantings with high productivity, the leaf area index (LAI) typically exceeds 1.5, and for some crops it can be considerably higher (Fig. 1). Under these conditions, fruit yield per 1m² of leaf area is expected to exceed 1kg. In this study, the Augustine variety exhibited a leaf area index of 1.35 and produced 1.8 kg of fruit per 1m² of leaf area. In contrast, the Inia variety had a slightly lower leaf area index, approximately 6% less than Augustine, and its fruit yield per unit leaf area was reduced by 1.8-fold, amounting to 1 kg/m².

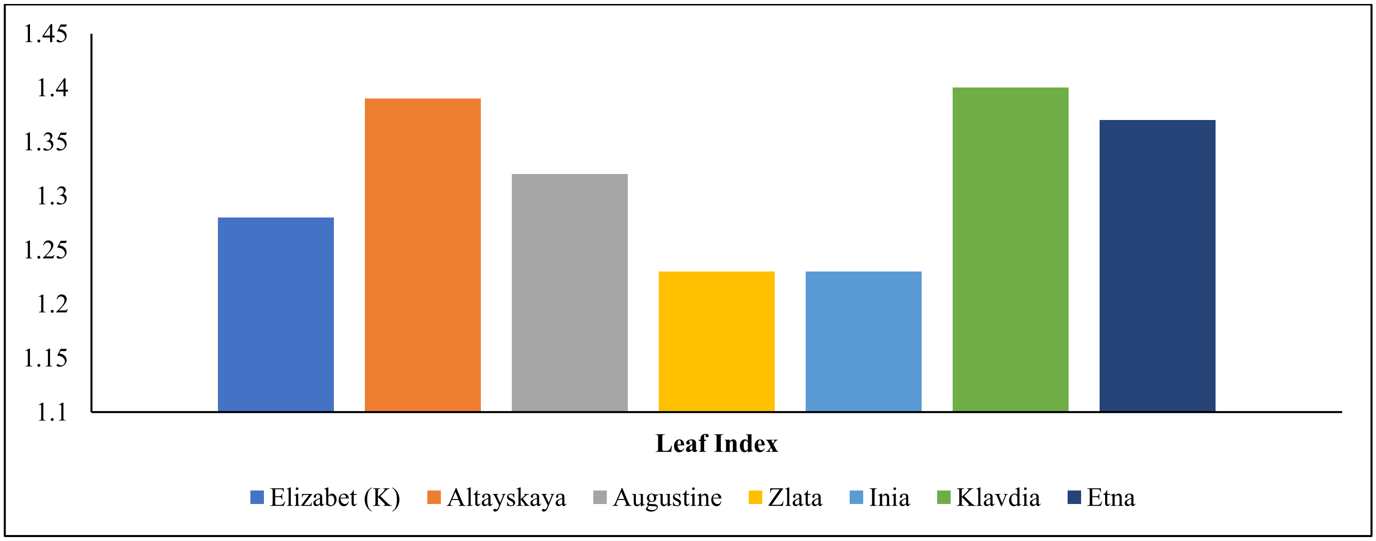

Figure 1. The value of the leaf index of the studied sea buckthorn varieties.

Biochemical Composition of Sea Buckthorn

Attention should also be given to leaf efficiency, specifically the area and number of leaves required for the formation of a single fruit. In the varieties Inia and Augustine, which reached full fruiting, these values were nearly identical, averaging 6cm² of leaf area and 1.5 leaves per fruit. Comparative analysis of the studied varieties for biochemical composition revealed no significant deviations; all varieties followed previously established trends in the accumulation of physiologically valuable components. Notably, the Altai variety exhibited the sweetest taste, with a sugar-acid ratio of 3.8, and also distinguished itself by a high carotenoid content, surpassing the control variety Elizaveta by 17.3% (Table 7). Biochemical composition was assessed only for varieties that produced sufficient fruit material (Augustine and Inia). Non-fruiting varieties could not be analyzed in year two, resulting in unavoidable dataset gaps.

Table 7. Biochemical composition of sea buckthorn fruits

Varieties	Average fruit weight (g)	Dry content (g)	Vitamin C (mg)	Sugars (%)	Acidity (%)	Carotenoids (mg)
Elizabet (K)	0.60	8.9	97.2	6.5	1.8	6.2
Altayskaya	0.56	9.1	107.8	7.3	1.9	7.5
Augustine	1.15	9	93.6	6.9	1.7	5.8
Zlata	-	-	-	-	-	-
Inia	0.65	8.8	98.5	6.7	2	6.7
Klavdia	0.71	8.7	96.4	6.8	2.1	6.5
Etna	0.73	9.1	101.5	6.6	1.8	6.3

DISCUSSION

Phenological analysis indicated that flowering of Altai sea buckthorn varieties in the foothill zone of the Almaty region occurs in mid-April, approximately 3–5 days earlier than black currant. Early flowering carries some risk of frost damage to floral organs; however, the morphological structure of sea buckthorn flowers mitigates these risks. Fruit ripening in this region occurs in the third decade of July, nearly a month earlier than in the Altai region, and high heat supply reduces variation in ripening times among varieties. In the absence of harvesting, fruits begin to wither by early August. Although sea buckthorn buds are tolerant to extreme temperatures, their resilience declines sharply after dormancy, and flowering under temperature extremes can affect reproductive potential (Ozherelieva, 2016).

Differences in vegetative development were also observed. According to the originator's morphological descriptions, the studied varieties were medium-sized. Bush heights ranged around 1 m, exceeding this in non-fruiting varieties such as Klavdia and Etna, suggesting accelerated generative development in Augustine and Inia, while other varieties lagged. The Zlata variety showed low adaptive potential, apparently responding negatively to high summer temperatures. Earlier generative development is a variable trait across sea buckthorn genotypes, consistent with phenotypically accelerated reproductive tendencies reported previously (Li & Schroeder, 1996; Corelli & Lakso, 2004).

The leaf area index (LAI) is a critical indicator of vegetative development and canopy efficiency, reflecting leaf area relative to land area. Optimal values for plantation productivity are typically 1.5–5 units, though super-intensive plantings may exceed this range (Wang, 2023). Leaf development affects productivity not only through leaf number and area but also via leaf morphology, including the ratio of spongy to palisade parenchyma, which influences vegetative and regenerative biology (Larbi *et al.,* 2015). In the meadow-garden, all studied varieties approached an LAI of 1.5 in the second year, with further increase expected in the third year as bush structure allows better illumination (Fu, 2014).

Fruit yield per unit leaf area reflects varietal intensity. The Altai Augustine variety significantly outperformed others, largely due to its large-fruitedness. While fruit mass in Inia was proportional to the mass of wood and leaves, in Augustine, fruit mass was relatively higher than vegetative mass. Climate influences fruit size; in moderate regions such as Issyk-Kul, Kyrgyzstan, Altai varieties showed a 20–25% increase in fruit mass, approaching the originator's specifications (Li & Schroeder, 1996). Optimized water and nutrient regimes can therefore maximize the genetically determined productivity potential of individual varieties (Corelli & Lakso, 2004).

High yields in the second year involve significant harvesting labor. Manual harvesting of small bushes is less efficient due to bending; however, cutting branches followed by shock freezing and fruit detachment has been effective worldwide (Oleichenko, 2023). In our experiments, compact domestically manufactured equipment allowed harvesting up to 500 kg in an 8-hour workday. Economic analysis showed that high-yielding, thornless varieties nearly recoup investment costs at a fruit purchase price of 2,000 tenge, even with a daily harvest of 15 kg per worker (Table 8). Major initial costs include seedlings, drip irrigation systems, and mulching installation. Domestic equipment meets local smallholder needs economically and with lower maintenance costs (Lewis *et al.,* 2022). Economic estimates were

based on current market prices and manual harvesting. Scenario-based variations (e.g., mechanization, labor cost changes, price fluctuations) were not included but should be evaluated in future studies.
Planning for market fluctuations in fruit prices, seedling costs, and labor remains essential (Wu *et al.*, 2024). Meadow-garden cultivation also requires fertilizers, bio-fungicides, and advanced bio-stimulants. Future expansions may incorporate drone-assisted foliar feeding and pest management to improve efficiency and reduce labor inputs (Kosachev *et al.,* 2021).

Table 8. Economic efficiency of sea buckthorn cultivation

Sr	Varieties	Yield t/ha	Costs thousand tenge/ha	Cost of harvest thousand tenge/ha	Cost price tenge/kg	Profit thousand tenge/ha	Profitability level- %
1	Elizabet (K)	1.0	30770	-	-	-	-
2	Avgustine	25	51170	50000	2468	-1170	-
3	Inia	13.4	41486	26800	3096	-14686	-

Economic Efficiency of Sea Buckthorn
The developed meadow-garden technology is economically efficient, with full recovery of capital costs achievable by the second year after planting. In the third year, profitability is expected to increase further through the harvesting method of cutting above-ground plant parts, followed by shock freezing and mechanical fruit removal.
Limitations
This study was conducted at a single location under specific climatic conditions, which limits the generalizability of the results. Only two varieties (Augustine and Inia) reached commercial fruiting in the second year; therefore, productivity comparisons among all genotypes were not possible at this early stage. Biochemical analyses were performed only for fruiting varieties, leaving gaps for cultivars that did not produce measurable yield. Long-term performance, stability of early fruiting, and varietal behavior across different regions and years remain outside the scope of the study. Additionally, detailed environmental monitoring such as soil moisture dynamics, nutrient fluctuations, and canopy microclimate was not included. The economic evaluation was performed using current cost structures and did not model alternative market or mechanization scenarios.

CONCLUSIONS
In the second year after planting the sea buckthorn meadow-garden, only two of the seven varieties developed by the M.A. Lisavenko Research Institute of Siberian Horticulture, Augustine and Inia, produced a commercial yield of 25 t/ha and 13.4 t/ha, respectively. Vegetative development at this stage was sufficient, with bush heights ranging from 81 cm in Zlata to 137 cm in Etna, and 3–5 large branches per bush bearing 143–173 increments. Fruit productivity relative to leaf area and wood mass reflected varietal intensity, with Augustine exhibiting the largest fruit size (1.15 g per fruit), twice that of the control variety Elizabet and 1.78 times greater than Inia. While achieving high yields in the second year entails considerable harvesting effort. Economic analysis indicated that high-yielding, thornless varieties such as Augustine can nearly fully recoup planting and maintenance costs at a purchase price of 2,000 tenge, even with a daily harvest of 15 kg per worker. In the third year, profitability is expected to remain high, even under reduced product prices, provided that harvesting employs cutting of above-ground plant parts, shock freezing, and mechanical fruit removal using specialized equipment. These results highlight the potential of Altai sea buckthorn varieties for early commercial production in meadow-garden systems under continental climatic conditions.

ACKNOWLEDGEMENTS
Not applicable

AUTHOR CONTRIBUTIONS
All the authors contributed equally to this research.

COMPETING OF INTEREST
No conflicts of interest have been disclosed by the authors.

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