

## RESEARCH ARTICLE

# Evaluation of Ten Cucumber (*Cucumis sativus* L.) Hybrids Under Greenhouse Conditions in the Aral Sea Region of Kazakhstan

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**Abstract:** Greenhouse cucumber production in the Aral Sea region of Kazakhstan faces unique challenges due to harsh climatic conditions and limited agricultural resources, making cultivar selection a critical determinant of productivity and economic viability. This study evaluated ten parthenocarpic smooth-fruited cucumber hybrids, Multistar F1, Melen F1, Hoyrat F1, Minmax F1, Lami F1, Infinity F1, Magnum F1, Sprint F1, Joki F1, and Kirton F1, under greenhouse conditions in 2024. Plants were grown in a small-volume hydroponic system using a substrate of 75% wood shavings and 25% rice husks, arranged in a randomized complete block design with three replications. Key performance indicators included fruiting onset, total yield (kg/m<sup>2</sup>), fruit count, average fruit weight, dry matter content, nitrate accumulation, and profitability index. Only Sprint F1 and Multistar F1 achieved the target fruiting onset of 45-46 days after germination. The highest yields were recorded for Melen F1, Hoyrat F1, Joki F1, and Kirton F1 (37.1-38.6 kg/m<sup>2</sup>), driven primarily by increased fruit weight, while Sprint F1 achieved 38.0 kg/m<sup>2</sup> through a combination of high fruit count and favorable average fruit weight. Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1 demonstrated high dry matter content and low nitrate accumulation, indicating strong market quality. Sprint F1, Melen F1, Joki F1, and Hoyrat F1 recorded the highest profitability indices (78.1-78.5%). Based on combined agronomic and economic performance, Sprint F1 and Melen F1 are recommended as the most suitable hybrids for commercial greenhouse cucumber production in the Aral Sea region of Kazakhstan.

**Keywords:** *Cucumis sativus*, Parthenocarpic Hybrids, Greenhouse Horticulture, Hydroponic Substrate, Yield Evaluation, Fruit Quality, Nitrate Accumulation, Aral Sea Region

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## Introduction

Cucumber (*Cucumis sativus* L.) is one of the most popular vegetable crops in the world, intended mainly for fresh consumption. It is a valuable source of vitamins, minerals, and antioxidants, making it an important component of a healthy diet [1, 2]. Due to its high yield, short growing cycle, and steady demand in both domestic and international markets, cucumber holds a significant place in the structure of greenhouse vegetable production.

Shifts in consumer preferences toward safe and environmentally friendly products have contributed to the active adoption of sustainable cultivation technologies. In developed countries, soilless cultivation systems and high-tech greenhouse structures have become widespread, offering a high degree of microclimate control and resource efficiency [3, 4]. This has made greenhouse cucumber production a highly efficient sector, and the area under protected cultivation continues to expand worldwide.

A key factor in increasing the economic efficiency of greenhouse production is the proper selection of hybrids that offer high yield, excellent fruit quality, resistance to biotic and abiotic stresses, and adaptability to modern cultivation technologies. According to various studies, cucumber yield can depend on variety by 20% or more - often substantially more, with observed differences ranging from ~50% to nearly double, depending on the variety and conditions [5-7]. In recent years, cucumber breeding has undergone significant changes. The emergence of new hybrids has substantially improved both yield and product quality, while also transforming production practices. The rapid turnover of varieties - especially under protected cultivation - means that the active use of a hybrid in commercial production rarely exceeds 5-7 years, and is often limited to just 2-3 years. This is due to both biological and market-driven factors.

With the growing commercialization of cucumber production, emphasis is placed on intensive greenhouse cultivation using early-ripening hybrids that combine high productivity with resistance to key phytopathogens. This strategy ensures a reliable supply of fresh cucumbers to meet sustained market demand [8]. Under these conditions, it is crucial for growers to stay informed about new breeding developments, test hybrids under their specific conditions, and adapt agronomic practices to match varietal characteristics. Even the most productive hybrids can only reach their full potential with appropriate agronomic support. As an object of intensive breeding, cucumber possesses vast genetic diversity, making the selection of suitable hybrids a highly complex task - especially in regions with unstable climatic conditions.

For this reason, studies on the adaptability of cultivars and hybrids are being conducted in various countries and remain globally relevant [2, 5, 8-18].

Such studies are particularly relevant and significant for the Aral Sea region, as they are being conducted here for the first time. The seed production market in Kazakhstan is characterized by a wide range of hybrids, predominantly of foreign breeding, while domestically bred seeds are virtually absent. Upon entering the market, these hybrids are evaluated solely based on DHS criteria (Distinctness, Uniformity, Stability), which is insufficient for informed decision-making regarding commercial cultivation. To achieve profitable yields, producers require objective data on potential productivity, fruit quality, and resistance to biotic and abiotic stresses.

Particular interest in greenhouse production is drawn to medium-sized parthenocarpic cucumbers, which are in high demand in local food markets due to their excellent marketability and seedless fruits. Their parthenocarpy and indeterminate growth habits make these hybrids ideal for vertical cultivation in greenhouses.

In this context, trials were conducted in the Aral region of Kazakhstan on ten parthenocarpic cucumber hybrids recommended by leading companies from the Netherlands and Russia for protected cultivation in Kazakhstan. The aim of these trials was to identify the most promising hybrids in terms of yield, fruit quality, and adaptability to local environmental conditions - thus addressing the needs of both growers and consumers. The results of such studies are essential for the introduction of resilient and high-performing cultivars into the region's commercial greenhouse production systems.

## Materials and Methods

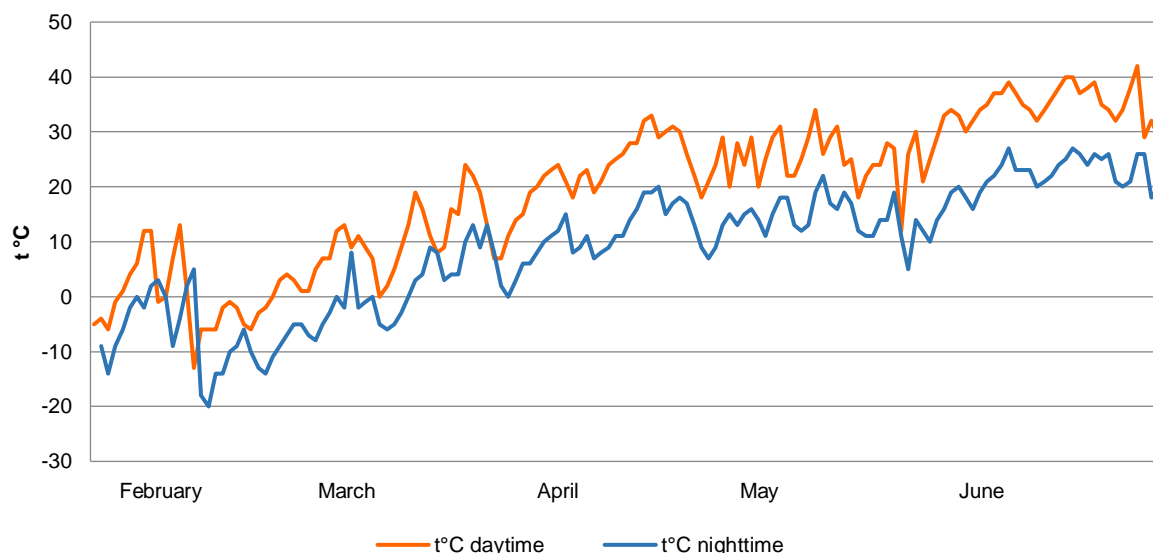
### Location and Experimental Conditions

The research on cucumber hybrid trials was conducted at the greenhouse facility of Korkyt Ata Kyzylorda University, located in the Aral Sea region of the Republic of Kazakhstan (geographic coordinates: 44°51'10.1" N, 65°30'33.1" E). The experiment was carried out during the winter-spring growing cycle from January to July 2024.

Kyzylorda Region belongs to the VII light zone of Kazakhstan, and its natural and climatic conditions allow for year-round cultivation of cucumbers under protected conditions. However, due to extremely high summer temperatures (reaching 36-48°C), cucumber cultivation during the summer becomes impractical. As a result, two growing cycles are commonly used in regional greenhouses: winter-spring (January-July) and autumn-winter (September-January).

During the autumn-winter period, with shorter daylight hours and predominantly cloudy weather, full plant development is not possible without supplemental lighting. However, the use of artificial lighting significantly increases production costs. Therefore, in this study, the winter-spring growing cycle was used, with limited supplemental lighting applied only during the seedling stage.

The climatic conditions during the research period were influenced by the sharply continental climate of the Kyzylorda Region, which is characterized by significant fluctuations in meteorological parameters on daily, monthly, and annual scales. The graph demonstrates a clear upward trend in temperature as the growing season progresses, with daytime temperatures peaking at 42°C in June. A pronounced diurnal temperature variation is observed throughout the entire period (Figure 1).



**Fig. 1: Meteorological conditions during the experimental research period**

During the experimental period, the average daytime air temperature in the greenhouse was 28.9°C, while the nighttime temperature averaged 19.2°C. Maximum temperatures reached up to 42.0°C, and minimum temperatures dropped to 16.1°C. These temperature conditions, along with the absence of supplemental lighting during the active vegetative stage, created a realistic cultivation model closely aligned with the typical protected-environment conditions of the region.

The soil cover of the region is characterized by the predominance of desert zone soils, including brown and sierozem soils, which are distinguished by low humus content and a high degree of salinity. These characteristics make them poorly suited-or even entirely unsuitable-for greenhouse production. Therefore, the use of soilless cultivation technologies is considered the most optimal approach for growing vegetable crops in greenhouses. The absence of natural organic substrates in the region, such as peat, along with the high cost of conventional substrates like mineral wool and coconut coir, significantly reduces the profitability of greenhouse vegetable production. This has necessitated the use of alternative substrates based on waste products from the woodworking and rice-processing industries. Previous studies have identified the optimal substrate composition for cucumber cultivation as a mixture of sawdust and rice husks in a 75:25 ratios [19]. This substrate composition was used in the present study.

The study was conducted in a 270 m<sup>2</sup> greenhouse designed for soilless vegetable cultivation. The greenhouse is equipped with a stationary gas-fired boiler, which ensures the maintenance of optimal temperature conditions during the cold season. To regulate the microclimate on hot days, an active ventilation and misting system is used, allowing for the maintenance of optimal air temperature and humidity levels.

## Plant Material and Cultivation Environment

In the region's greenhouse production, preference is generally given to vegetable varieties and hybrids of foreign origin. Accordingly, ten parthenocarpic medium-fruited cucumber hybrids of the European type-also known as "Dutch type"-were selected for testing, predominantly from Dutch and French breeding programs (Table 1).

**Table 1: Cucumber hybrids used in the experiment**

Hybrid	Production company	Origin
Multistar F1 St	Rijk Zwaan	Netherlands
Melen F1	Enza Zaden	Netherlands
Hoyrat F1	Enza Zaden	Netherlands
Minmaks F1	Enza Zaden	Netherlands
Lami F1	Enza Zaden	Netherlands
Sprint F1	Vilmorin	France
Joki F1	Vilmorin	France
Kirton F1	Vilmorin	France
Magnum F1	Nunhems	Netherlands
Infinity F1	Nunhems	Netherlands

In selecting the hybrids for the study, in addition to fruit type and size, several other important criteria were considered: maturity period, shade tolerance, resistance to temperature fluctuations, and disease resistance, especially to powdery mildew and downy mildew.

Plant growth was facilitated by a small-volume hydroponic technique. The experimental setup employed a randomized complete block design (RCBD), incorporating three repetitions arranged on shelving. Random assignment of treatments was achieved through the utilization of the random number generator within Microsoft Excel. A planting density of 2.2 plants per square meter was maintained, aligning with established practices for high-yield cucumber cultivation in greenhouses.

The hybrid Multistar F1, recommended by Rijk Zwaan for cultivation in Kazakhstan and known for its stable yield and high fruit quality, was used as the standard (control) variety.

Seeds of the tested hybrids were sown on February 1, 2024, into 10 cm diameter pots filled with a peat-based substrate enriched with nutrients and adjusted to an optimal pH of 5.5. Before emergence, the temperature was maintained at 24-27 °C; after emergence, daytime temperatures were held at 21-23 °C, and nighttime at 18-19 °C.

Supplemental lighting was used during the seedling stage as follows: Days 1-3: 24 hours of light, Days 4-10: 18 hours, Days 11-20: 16 hours, From day 21 until transplanting: 12 hours.

To ensure optimal light conditions, 12-14 days after emergence, plant spacing was adjusted to a density of 20-28 plants/m<sup>2</sup>.

Cucumber seedlings were transplanted into the greenhouse on February 25, when the plants had developed their fourth true leaf. The cucumbers were grown in 30-liter grow bags filled with a substrate composed of 75% wood shavings and 25% rice husk. The substrate was pre-moistened with a nutrient solution at a concentration of 3.0-3.5 mS/cm<sup>2</sup> using a drip irrigation system. Three plants were placed in each bag, connected to the drip system, and tied to a trellis using hooks.

For the first three days after transplanting, the air temperature was maintained at 17-18 °C, and then increased by 1 °C daily until the optimal levels were reached (Table 2).

**Table 2: Temperature regime in the greenhouse during cucumber cultivation**

Vegetation Period	Daytime (Sunny Weather)	Daytime (Cloudy Weather)	Night time
Before fruiting	22-24 °C	20-22 °C	17-18 °C
During fruiting period	24-26 °C	22-24 °C	18-20 °C

Relative humidity was maintained at 70-75% before the start of fruiting, and 75-80% during the active fruiting period. As the plants grew, they were trained according to the following scheme: removal of fruit set in the leaf axils up to a height of 40 cm and removal of lateral shoots up to 60 cm; further, lateral shoots were pinched after the formation of two fruit sets. The main vine was laid along the trellis, then pinched above the third node, and three shoots were lowered downward with pinching every 50 cm.

A balanced nutrient solution, tailored to the plant's developmental stage, was used to supply essential elements for plant nutrition (Table 3).

**Table 3: Composition of the nutrient solution for cucumber cultivation, ppm**

Vegetation Period	Nutrient elements											
	N (NO <sub>3</sub> <sup>-</sup> )	N (NH <sub>3</sub> <sup>+</sup> )	P	K	Ca	Mg	Fe	Mn	B	Cu	Zn	Mo
Before fruiting	200	15	45	275	220	50	1,5	0,75	0,5	0,1	0,2	0,05
During fruiting period	200	15	45	300	175	50	1,0	0,75	0,5	0,1	0,2	0,05

The concentration of the nutrient solution (measured by EC) ranged from 1.7 to 3.0, depending on the plant development stage. The pH of the nutrient solution was maintained at 5.5-6.0 by adding nitric acid.

Irrigation was carried out daily at specific times, with the duration of each session adjusted to achieve target drainage percentages based on the total volume of nutrient solution applied: 7:00 - 0%; 9:00 - 3%; 10:00 - 6%; 11:00 - 12%; 12:00 - 30%; 13:00 & 15:00 - 25%; 17:00 - 10%.

Irrigation and plant feeding were conducted in automatic mode using injector "Dozotron" and an electronic timer. Equipment operation was adjusted daily based on monitoring the volume of solution applied (ml), its concentration (EC), and pH-both in the nutrient solution and in the drainage.

The growing period lasted up to 110 days after transplanting, with the harvest period starting 11-12 weeks after planting. Cucumber harvesting began 25-30 days after transplanting and was conducted daily. The harvest was classified according to the standard quality categories defined in GOST 1726-85, Fresh Cucumbers. Specifications. In calculating marketable yield, the total of first- and second-quality fruits was considered, while total yield included all three quality categories.

## Observations and Data Collection in the Experiment

During the course of the experimental research, the following activities were conducted:

- Phytomonitoring studies, which included recording key microclimate parameters (air temperature and relative humidity), as well as monitoring the irrigation and nutrient supply regime. This was achieved by regularly measuring the volume, Electrical Conductivity (EC), and acidity (pH) of both the nutrient and drainage solutions.
- Phenological observations were made to track plant growth and development. Key stages were recorded: sowing date, seedling emergence, transplanting into the greenhouse, onset of flowering, and beginning of fruiting.
- Biometric measurements were taken on 10 marked plants in each replication. Indicators such as the number of fruits per plant and average fruit weight were measured, enabling the calculation of yield. Yield per unit area (kg/m<sup>2</sup>) was calculated based on the average yield per plant and planting density.

Fruit quality assessment was carried out in accordance with established standards, including the evaluation of organoleptic characteristics [20], soluble solids content [21], sugar content [22], ascorbic acid content [23], and nitrate ion content [24].

Analysis of variance (ANOVA) was conducted in accordance with the methodology described by Dospekhov [25], using the built-in Data Analysis Toolpak in Microsoft Excel for Windows, which is widely used in the design of agricultural experiments.

To assess the economic efficiency of cultivating cucumber hybrids, production costs were analyzed and the cost price, revenue, profit, and profitability level were calculated.

## Results

During phenological observations of the studied cucumber hybrids, the following dates were recorded: sowing, seedling emergence, transplanting, onset of flowering, and onset of fruiting (Table 4). Based on these data, the duration of each phenological phase was calculated, including the phases "sowing-emergence," "emergence-flowering," "emergence-fruiting," and the "fruiting period" (Table 5).

Based on phenological observations, the duration of the main developmental phases was determined for 10 cucumber hybrids: Multistar F1 (St), Melen F1, Hoyrat F1, Lami F1, Minmaks F1, Sprint F1, Kirton F1, Joki F1, Magnum F1, and Infinity F1.

The duration of the period from sowing to seedling emergence ranged from 4 to 6 days. For most of the studied hybrids, full emergence occurred on day 5, similar to the standard hybrid Multistar F1. The shortest period was observed in Sprint F1 and Kirton F1 (4 days), while the longest was in Lami F1 and Magnum F1 (6 days). The phase from emergence to flowering lasted 33 to 36 days. The earliest onset of flowering was observed in the hybrid Sprint F1 (33 days), whereas the latest flowering was recorded in Magnum F1 (36 days).

**Table 4: Dates of phenological development stages in different cucumber hybrids**

Hybrid	Sowing	Emergence	Transplanting	Flowering	Fruiting
Multistar F1 St		06.02		12.03	24.03
Melen F1		06.02		13.03	24.03
Hoyrat F1		06.02		14.03	25.03
Minmaks F1		06.02		14.03	25.03
Lami F1		07.02		16.03	27.03
Sprint F1	01.02	05.02	25.02	10.03	22.03
Joki F1		06.02		14.03	24.03
Kirton F1		05.02		11.03	23.03
Magnum F1		07.02		16.03	27.03
Infinity F1		06.02		14.03	26.03

**Table 5: Duration of phenological development phases in cucumber hybrids (days)**

Hybrid	From Sowing to Emergence	From Emergence to Flowering	From Emergence to Fruiting	Fruiting Period
Multistar F1 St	5	34	46	83
Melen F1	5	34	46	83
Hoyrat F1	5	35	47	82
Lami F1	6	35	48	81
Minmaks F1	5	35	47	82
Sprint F1	4	33	45	84
Kirton F1	4	34	46	83
Joki F1	5	35	46	83
Magnum F1	6	36	48	81
Infinity F1	5	35	48	81

The period from emergence to the start of fruiting ranged from 45 to 48 days. The shortest duration was observed in Sprint F1 (45 days) and the longest in Lami F1, Magnum F1, and Infinity F1 (48 days). The duration of the fruiting phase also showed slight variation-ranging from 81 to 84 days. The longest fruiting period was noted in Sprint F1 (84 days), while the shortest was in Lami F1, Magnum F1 and Infinity F1 (81 days).

Overall, Sprint F1 was characterized by the shortest vegetative period and the earliest onset of flowering and fruiting, which may be advantageous when cultivating under a short growing season.

Cucumber harvesting was carried out from March 22 to June 15. The end of the harvest period was associated with a sharp rise in daytime temperatures exceeding +40 °C, which adversely affects plant growth and fruiting.

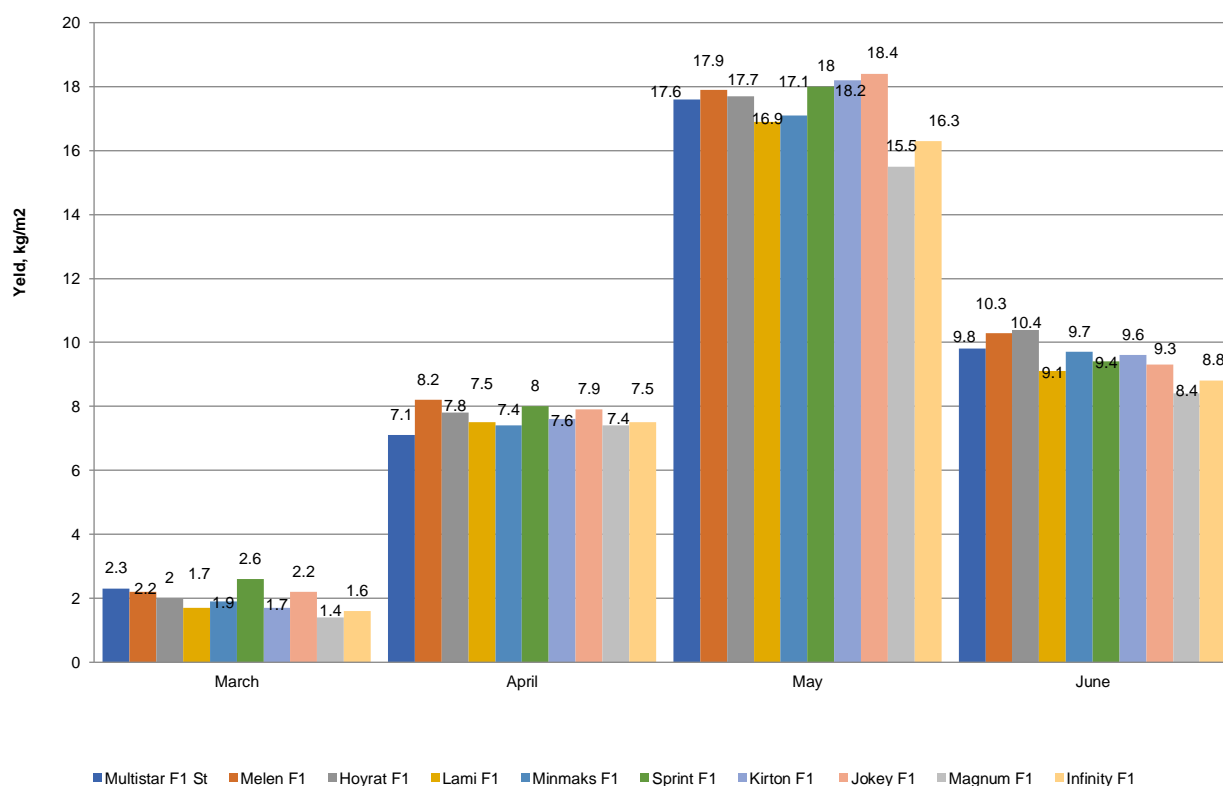
Fruits harvested on or before May 1 were considered as early yield. This part of the yield is particularly important for assessing the earliness of hybrids and the economic efficiency of their cultivation in protected environments or under early open-field sowing.

The harvested cucumbers were classified according to the national standard (GOST 1726-85. Fresh cucumbers. Specifications), which defines the following quality categories:

- First grade - fruits of correct shape, free of mechanical damage, and of standard size
- Second grade - fruits with minor deviations in shape or size and slight defects
- Non-standard produce - fruits not meeting the main criteria but suitable for processing or technical use

The total yield included all harvested produce regardless of quality, while the marketable yield included only first- and second-grade fruits suitable for fresh market sales.

The yields obtained were analyzed, and the results are presented in Figure 2 and Table 6.



**Fig. 2: Dynamics of cucumber harvest**

Analysis of Variance (ANOVA) revealed statistically significant differences among the studied cucumber hybrids for all yield parameters at the 5% significance level: for early yield -  $F_f > F_{05} = 16.20 > 2.40$ , for total yield -  $F_f > F_{05} = 33.30 > 2.40$ , and for marketable yield -  $F_f > F_{05} = 45.30 > 2.40$ . These results indicate a reliable influence of varietal characteristics on productivity.

The greatest increase in early yield compared to the standard (by 0.7-1.2 kg/m<sup>2</sup>) was confirmed for three hybrids: Sprint F1, Melen F1, and Joki F1. These hybrids stood out not only for their earliness but also for the high quality of their early produce. The highest early yield was recorded for Sprint F1 (10.6 kg/m<sup>2</sup>), confirming its early maturity and strong potential for early-season production.

The total yield among the evaluated hybrids varied from 32.7 kg/m<sup>2</sup> in Magnum F1 to 38.6 kg/m<sup>2</sup> in Melen F1. Five hybrids outperformed the standard in total yield, with a statistically significant increase observed in Sprint F1, Melen F1, Joki F1, and

Hoyrat F1 (by 1.1-1.8 kg/m<sup>2</sup>). These hybrids demonstrated stable productivity throughout the entire fruiting period, including the peak and late phases.

**Table 6: Yield and fruit productivity indicators of cucumber hybrids**

Hybrid	Early, kg/m <sup>2</sup>	Total, kg/m <sup>2</sup>	Standard		Number of fruits per plant	Average fruit weight, g
			kg/m <sup>2</sup>	% of Total		
Multistar F1 St	9.4	36.8	36.4	98.9	117	143.0
Melen F1	10.4	38.6	38.3	99.2	114	153.9
Hoyrat F1	9.8	37.9	37.5	98.9	111	155.2
Lami F1	9.2	35.2	34.9	98.6	109	146.8
Minmaks F1	9.3	36.1	35.6	99.1	110	149.2
Sprint F1	10.6	38.0	37.8	99.2	119	145.1
Kirton F1	9.3	37.1	36.6	98.8	115	146.6
Joki F1	10.1	37.8	37.5	98.5	102	168.4
Magnum F1	8.8	32.7	32.2	98.7	103	144.3
Infinity F1	9.1	34.2	33.8	99.5	104	149.5
LED <sub>05</sub>	0.42	0.94	0.83	-	4.3	4.5

Meanwhile, analysis showed a significant decrease in yield for Magnum F1: early yield was 0.6 kg/m<sup>2</sup> lower, and total yield 4.1 kg/m<sup>2</sup> lower than the standard. This suggests a limited potential of this hybrid under the experimental conditions and its relative unsuitability for early commercial production.

Standard yield (first and second grade) comprised more than 98% of the total yield for most hybrids, with the highest share observed in Infinity F1 (99.5%), indicating high fruit quality. The lowest proportion of marketable fruits was found in Joki F1 (98.5%), which is still considered high.

Significant differences were also observed in the number of fruits per plant ( $F_f > F_{05} = 16.70 > 2.40$ ) and average fruit weight ( $F_f > F_{05} = 23.3 > 2.40$ ). The highest fruit counts per plant were recorded for Sprint F1 (119 fruits) and Multistar F1 St (117 fruits), making them promising candidates for intensive cultivation technologies, especially when combined with high early yields.

Average fruit weight ranged from 143.0 g (Multistar F1 St) to 168.4 g (Joki F1). The highest fruit weights, significantly exceeding the standard, were found in Melen F1 (174.3 g), Joki F1 (168.4 g), and Sprint F1 (167.7 g). Hybrids with heavier fruits are potentially more attractive for the fresh market, particularly in the premium segment.

Statistically significant differences between hybrids were confirmed by the LSD<sub>0.5</sub> values, which were: Early yield - 0.42 kg/m<sup>2</sup>; Total yield - 0.94 kg/m<sup>2</sup>; Standard yield - 0.83 kg/m<sup>2</sup>; Number of fruits - 4.3 fruits; Fruit weight - 4.5 g. Thus, the differences between hybrids across several traits are statistically valid and can serve as a basis for comparative assessment and selection of the most promising forms.

A correlation analysis between yield and productivity traits (number and weight of fruits) was also conducted to determine their influence on total yield. It was found that the correlation between the studied traits was average and amounted to between yield and number of fruits -  $r = 0.589$ , and between yield and average fruit weight -  $r = 0.432$ . This indicates that the number of fruits has a more significant impact on yield level compared to the weight of a single fruit (Figure 3).

To assess the quality and environmental safety of the cucumber harvest, organoleptic and physicochemical characteristics of the fruits were analyzed. In terms of appearance, internal structure, taste, and aroma, all studied hybrids met the requirements of GOST 1726-85, Fresh cucumbers. Specifications. The cucumber fruits were fresh, whole, not misshapen, healthy, uncontaminated, without mechanical damage, with peduncles, firm flesh, underdeveloped watery non-fibrous seeds, and characteristic shape, color, taste, and aroma typical of their botanical variety. The hybrids had fruit lengths ranging from 16 to 20 cm, which classifies them as medium-fruited varieties (14 to 25 cm according to the classification). The share of non-standard produce was 0.5-1.5%, which is well within the GOST-permitted limit of up to 10%. The results of biochemical analysis of quality indicators of cucumber hybrids are presented in Table 7.

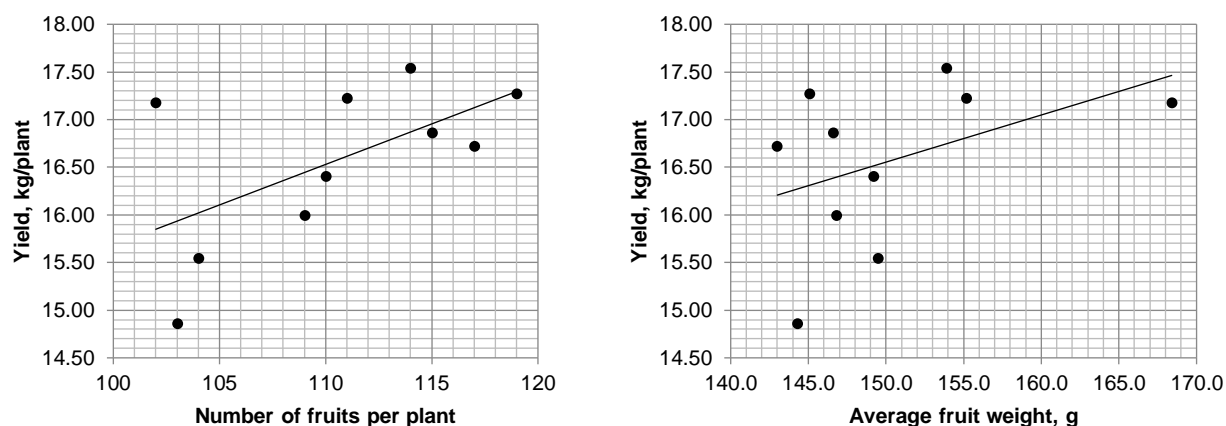


Fig. 3: The relationship between the yield of cucumbers and the components of the crop

Table 7: Biochemical composition of fruits of various cucumber hybrids

Hybrid	Dry matter, %	Total sugar, %	Ascorbic acid, mg/100 g	Nitrate (NO <sub>3</sub> <sup>-</sup> ), mg/kg
Multistar F1 St	4.34	2.80	6.97	95.2
Melen F1	4.43	2.84	6.93	90.4
Hoyrat F1	4.40	2.82	6.92	92.2
Minmaks F1	4.31	2.78	6.91	96.2
Lami F1	4.26	2.76	6.84	99.3
Sprint F1	4.39	2.82	6.92	92.3
Joki F1	4.38	2.83	6.94	92.1
Kirton F1	4.35	2.79	6.98	92.5
Magnum F1	4.09	2.71	6.85	107.6
Infinity F1	4.17	2.75	6.83	101.6
LED <sub>05</sub>	0.12	-	-	1.07

Analysis of Variance (ANOVA) of quality traits revealed significant differences for only two criteria: dry matter content ( $F > F_{05} = 6.52 > 2.40$ ) and nitrate ion content ( $F > F_{05} = 210.40 > 2.40$ ). This indicates a varietal dependency specifically for these quality characteristics. Regarding dry matter content, the values for the standard cultivar Multistar F1 St (4.34%) were slightly exceeded (by 0.01-0.09%) by the hybrids Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1. However, these differences were not statistically significant, as they did not surpass the threshold of  $LSD_{0.5}$  (0.12%). Significantly lower dry matter content was observed in the fruits of Magnum F1 (4.09%) and Infinity F1 (4.17%), which differed reliably from the standard.

Regarding dry matter content, the values for the standard cultivar Multistar F1 St (4.34%) were slightly exceeded (by 0.01-0.09%) by the hybrids Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1. However, these differences were not statistically significant, as they did not surpass the threshold of  $LSD_{0.5}$  (0.12%). Significantly lower dry matter content was observed in the fruits of Magnum F1 (4.09%) and Infinity F1 (4.17%), which differed reliably from the standard.

In terms of nitrate ion content, statistically significant differences from the standard Multistar F1 St (95.2 mg/kg) were found in 9 out of 10 studied hybrids. The hybrids Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1 demonstrated reduced nitrate accumulation-2.7-4.8 mg/kg less than the standard. In contrast, the hybrids Lami F1, Infinity F1, and especially Magnum F1 exhibited elevated nitrate levels-4.1-12.4 mg/kg higher than the control.

The analysis of sugar and ascorbic acid content revealed no statistically significant differences among the hybrids. The F-value ( $F = 1.20 < F_{05} = 2.40$ ) confirms the null hypothesis ( $H_0$ ) of no varietal effect on these indicators. Differences in sugar content between hybrids were minimal: values ranged from 2.71% (Magnum F1) to 2.84% (Melen F1). Although the

differences were slight, the highest values were recorded for Melen F1, Joki F1, and Hoyrat F1, which positively affects the taste qualities of the fruits. Ascorbic acid content remained within a narrow range - from 6.83 to 6.98 mg/100 g. The maximum value was recorded in Kirton F1 (6.98 mg/100 g), and the minimum in Infinity F1 (6.83 mg/100 g), indicating negligible variation between the samples for this trait. Thus, the levels of sugars and ascorbic acid in the fruits of the studied hybrids can be considered stable and largely independent of varietal origin.

Overall, the hybrids Melen F1, Hoyrat F1, Sprint F1, and Joki F1 demonstrated the most balanced indicators in terms of dry matter, sugars, and ascorbic acid content, along with relatively low nitrate levels, which allows them to be recommended as promising cultivars in terms of product quality and safety. Table 8 presents the cost structure for cultivating cucumber hybrids.

**Table 8: Cost structure of cucumber hybrid cultivation per 1 m<sup>2</sup>**

Cost items	US\$	%
Gas (for heating)	3.01	33.8
Electricity	1.78	20.0
Water	0.16	1.8
Fertilizers	2.64	29.6
Seeds	0.27*	3.0
Consumables	1.04	11.7
<b>Total</b>	<b>8.91</b>	<b>100.0</b>

### Average Seed Cost for the Studied Hybrids

The cost of cultivating cucumber hybrids amounted to 8.91 US\$/m<sup>2</sup>. The majority of the costs (83.4%) are associated with maintaining an optimal microclimate and providing the necessary level of plant nutrition, including expenditures on gas for heating (33.8%), electricity for greenhouse equipment operation (20.0%) and fertilizers for the nutrient solution (29.6%). The remaining costs are attributed to consumables (11.7%), seeds (3.0%), and water (1.8%).

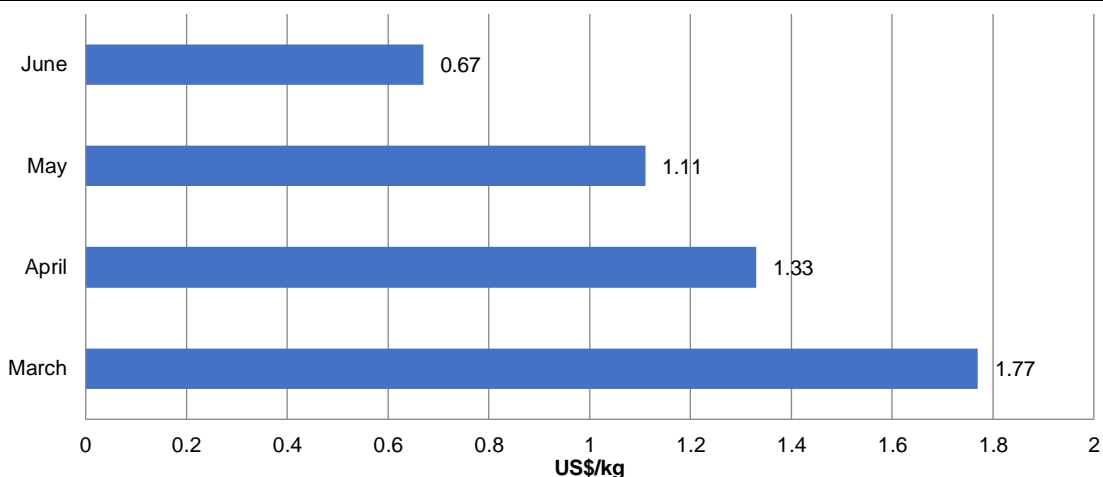
Table 9 presents data on production cost, revenue, profit, and profitability for 10 cucumber hybrids.

**Table 9: Economic efficiency of cultivating various cucumber hybrids**

Hybrid	Cost Price, US\$/m <sup>2</sup>	Revenue, US\$/m <sup>2</sup>	Profit, US\$/m <sup>2</sup>	Profitability, %
Multistar F1 St	8.96	39.57	30.62	77.4
Melen F1	8.97	41.53	32.55	78.4
Hoyrat F1	8.87	40.48	31.61	78.1
Lami F1	8.89	37.80	28.91	76.5
Minmaks F1	8.91	38.64	29.74	77.0
Sprint F1	8.90	41.48	32.58	78.5
Kirton F1	8.88	39.71	30.83	77.6
Joki F1	8.91	41.02	32.10	78.3
Magnum F1	8.87	35.12	26.25	74.7
Infinity F1	8.91	36.76	27.85	75.8

The cost price of cultivating cucumber hybrids varied slightly depending on seed cost - from 8.87 to 8.97 US\$ per 1 m<sup>2</sup>. The cost price of cultivating cucumber hybrids varied slightly depending on seed cost - from 8.87 to 8.97 US\$ per 1 m<sup>2</sup>. Revenue from product sales depended on the harvest dynamics (Figure 2) and the market price during the harvest period (Figure 4).

The highest revenue from product sales was generated by the hybrids Melen F1 (US\$ 41.53), Sprint F1 (US\$ 41.48), and Joki F1 (US\$41.02). These same hybrids also demonstrated the highest profit figures, amounting to US\$ 32.58, US\$ 32.55, and US\$ 32.10 respectively. In terms of both revenue and profit, Hoyrat F1 and Kirton F1 also outperformed the standard hybrid Multistar F1 St (US\$ 39.57/m<sup>2</sup> and US\$ 30.62/m<sup>2</sup> respectively). These hybrids generated revenue of US\$40.48 and US\$39.71, and profits of US\$31.61 and US\$ 30.83, respectively. The lowest economic performance was recorded for the hybrid Magnum F1, with revenue of US\$ 35.12/m<sup>2</sup> and profit of US\$26.25/m<sup>2</sup>.



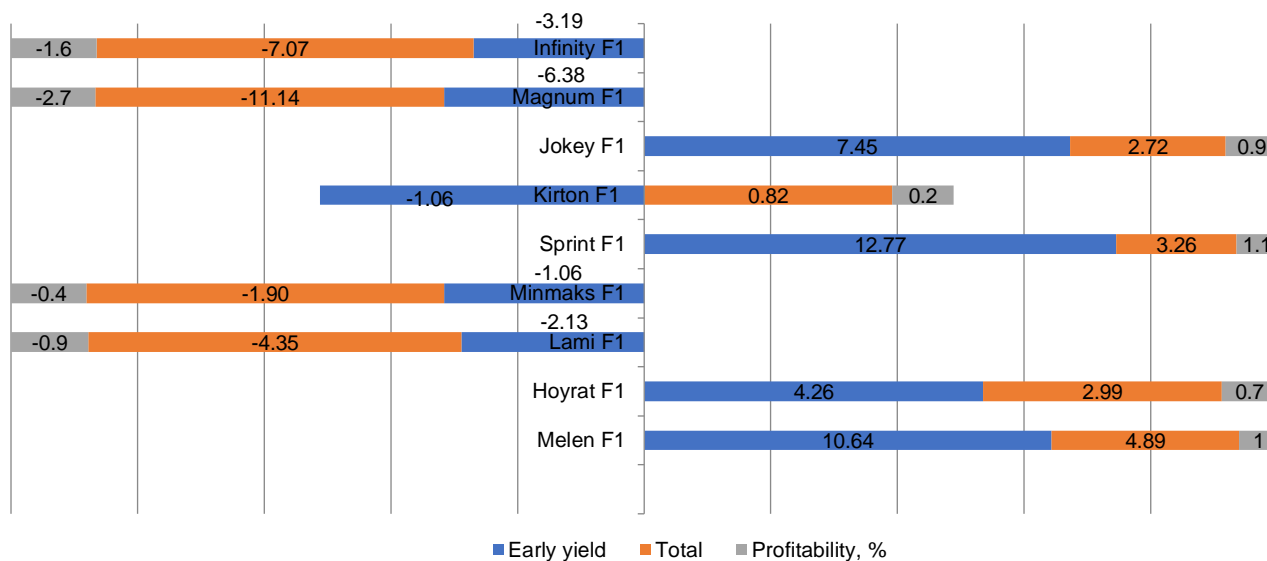
**Fig. 4: Dynamics of fresh cucumber prices**

The profitability of the studied hybrids remained at a high level, ranging from 74.7% to 78.5%. Five hybrids demonstrated profitability higher than that of the standard hybrid Multistar F1 St (77.4%). The top performers in this regard were Sprint F1 (78.5%), Melen F1 (78.4%), Joki F1 (78.3%), and Hoyrat F1 (78.1%). The lowest profitability levels were observed in the hybrids Magnum F1 (74.7%) and Infinity F1 (75.8%).

The correlation analysis conducted between the profitability level and the yield of the studied hybrids showed that profitability has a positive dependence on both early yield and total yield. However, early yield has a greater impact, with a correlation coefficient of  $r = 0.87$ , compared to  $r = 0.81$  for total yield.

The chart (Figure 5) clearly illustrates the following trend: the higher the share of early yield, the higher the profitability of the hybrid. In particular, hybrids with negative profitability values, such as Magnum F1, Infinity F1, and Lami F1, show low or even negative early yield indicators, which significantly reduces their economic efficiency.

Conversely, hybrids with the highest early yields - Sprint F1, Joki F1 and Melen F1 - demonstrate high profitability, despite possible differences in total yield volumes. This is explained by the fact that during the early harvest period, market prices for produce are generally higher, allowing for more profitable sales and thus significantly increasing revenue.



**Fig. 5: Relationship between profitability and early and total yield in different hybrids (Values relative to the standard hybrid Multistar F1 St)**

## Discussion

According to the characteristics declared by the producers, only the Multistar F1 St hybrid belongs to the medium-maturity group, with a maturation period of 46-50 days after germination. The remaining hybrids under study are classified as early-maturing, with a declared maturation period of 30-45 days. However, based on the data obtained in this study, only two hybrids-Sprint F1 and Multistar F1 St-demonstrated fruiting start dates that corresponded to the declared timeframes. In the other hybrids, the beginning of harvest occurred later than indicated, which may be attributed to the specific agro-climatic conditions of the experiment.

Since the cucumbers were grown without supplemental lighting during the relatively short daylight period in February-March (from 9 h 50 min to 12 h 47 min) and under a high number of cloudy days (16 in February and 20 in March), the main reason for the delayed onset of fruiting was a lack of solar radiation. In greenhouse conditions, radiation and temperature are the key factors determining plant metabolic activity. Their deficiency has a significant impact on plant growth and development, including photosynthetic activity and fruit formation capacity [11, 26]. In this experiment, the limiting factor that constrained plant growth and development was precisely the radiation deficit.

The shortest period from flowering to technological maturity was 11 days, observed in the Sprint F1 hybrid. In other hybrids, the development of a uniform cylindrical shape and achievement of market maturity occurred on days 12-13 after flowering. These findings are consistent with other studies, which report that cucumber fruits reach uniform diameter along their length by day 12-15 after flowering, and as early as day 11 in spring conditions [14, 27]. This supports the validity of the observations made in this study.

The minimum number of days to the first fruit set after emergence was observed in the hybrid Sprint F1 - 45 days. It was followed by Multistar F1 St, Melen F1, Kirton F1, and Joki F1 (46 days), then Hoyrat F1, and Minmaks F1 (47 days). The latest to begin fruiting were Lami F1, Magnum F1, and Infinity F1 (48 days). The maturation rate of cucumber hybrids was determined by their genotype and the plant's ability to respond to environmental conditions. Tolerance to abiotic stress factors enhances or suppresses the expression of inherited traits, including the transition rate to the generative phase, flowering time, and fruiting onset. In greenhouse conditions, where environmental parameters are only partially controlled, physiological stress tolerance plays a key role in realizing the hybrid's potential for early maturity [28-31].

Yield is one of the key factors in selecting a hybrid for profitable cultivation under protected conditions. The highest early yield values were recorded for the hybrids Sprint F1, Melen F1, and Joki F1, indicating their earliness and significant potential for early-season production, when market prices are most favorable. In terms of total yield, four hybrids - Sprint F1, Melen F1, Joki F1, and Hoyrat F1 - demonstrated the best performance, providing high and stable productivity throughout the entire fruiting period. These results confirm their suitability for intensive greenhouse production aimed at maximizing yield per unit area. At the same time, the hybrid Magnum F1 showed a statistically significant reduction in both early and total yield compared to the standard, indicating limited adaptability and lower efficiency under the conditions of the experiment, thereby reducing its feasibility for use in commercial vegetable production.

It should be noted that yield is determined by the combined effect of two main components - the number of fruits formed per plant and the average fruit weight [5, 11, 28], which must be taken into account when comparing the productivity of different hybrids.

The conducted correlation analysis of varietal traits showed that the relationship between yield and fruit number was moderately positive and stronger ( $r = 0.589$ ) than the correlation between yield and average fruit weight ( $r = 0.432$ ). Nevertheless, the productivity analysis of the studied hybrids indicates that both factors - fruit number and fruit weight - had a significant impact on total yield formation.

Among the five hybrids that outperformed the standard Multistar F1 St in total yield, only Sprint F1 demonstrated a simultaneous advantage in both fruit number and fruit weight. However, its yield was not the highest among the studied hybrids. The other hybrids - Melen F1, Hoyrat F1, Joki F1, and Kirton F1-exceeded the standard primarily due to higher fruit weight. These hybrids showed a more pronounced percentage increase in average fruit weight than in fruit number, suggesting different mechanisms of productivity enhancement among genotypes.

Thus, when selecting the highest-yielding hybrids, it is important to consider a balanced combination of fruit number and weight, giving preference to those genotypes that demonstrate an optimal ratio of these components.

As shown in the studies by Setyaningastuti & Taryono [32], Golabadi et al. [33], Shetty & Wehner [34], and Choubey et al. [35] the heritability of fruit number is higher than that of individual fruit weight, and this trait is closely correlated with overall yield. However, the authors also note that yield components and total plant productivity are significantly influenced by environmental factors, particularly under conditions of strong inter-trait correlations. Fruit number is less dependent on external factors, whereas the development of large fruits approaching their genetic potential is more strongly affected by agronomic practices and climate conditions. Therefore, the high fruit weight in a hybrid may result from its adaptability to local agro-climatic conditions [28, 35].

Accordingly, the optimal strategy in cucumber breeding and cultivation may involve initial selection for high fruit number, followed by consideration of fruit weight as a secondary yield indicator - an approach supported by data from Soleimani et al. [5].

Growers are interested in varieties that ensure not only maximum yield but also high quality of the vegetable products. Quality standards based on external characteristics - such as size and shape, color and appearance - as well as freshness under normal conditions and the absence of physiological disorders and defects, serve as objective indicators of a vegetable's market value [36]. All the studied hybrids met the quality requirements of GOST 1726-85 (Fresh Cucumbers. Specifications) based on organoleptic characteristics confirm their suitability for fresh-market sale, while the low share of substandard produce indicates a high level of marketable yield.

Analysis of variance (ANOVA) revealed statistically significant differences between hybrids only in terms of dry matter content and nitrate ions ( $F_f > F_{05}$ ), indicating that these traits are varietal-dependent. This finding aligns with previous studies on agrochemical and biochemical evaluation of vegetable crops, which conclude that dry matter and nitrate [37, 38].

Specifically, the dry matter content in Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1 slightly exceeded that of the standard Multistar F1 St (4.34%) by 0.01-0.09%, though these differences were not statistically significant, as they did not surpass the LSD<sub>05</sub> threshold (0.12%). Conversely, hybrids Magnum F1 (4.09%) and Infinity F1 (4.17%) had significantly lower dry matter content, which may suggest reduced suitability for storage and transportation, given that higher dry matter is associated with denser tissues and greater resistance to damage [39].

Regarding nitrate content, statistically significant differences were observed for most hybrids compared to the control. Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1 showed reduced nitrate accumulation, which is favorable in terms of compliance with ecological safety standards. According to sanitary regulations (TR CU 021/2011), the maximum permissible nitrate level for fresh cucumbers grown in protected environments is 400 mg/kg. In contrast, elevated nitrate levels were recorded in Lami F1, Infinity F1, and especially Magnum F1 (4.1-12.4 mg/kg above the standard), indicating the need for stricter nitrogen management when cultivating these hybrids.

The analysis of sugar and ascorbic acid content revealed no statistically significant differences ( $F_f = 1.20 < F_{05} = 2.40$ ), supporting the conclusion that these indicators are not variety-dependent under the given growing conditions. Nonetheless, slight advantages in sugar content were observed in Melen F1, Joki F1, and Hoyrat F1 (up to 2.84%), potentially enhancing fruit flavor - a key factor in consumer perception [40, 41]. Ascorbic acid content varied within a narrow range (6.83-6.98 mg/100 g), confirming its stability as a trait relatively unaffected by varietal differences when environmental conditions are uniform [42].

Overall, the Melen F1, Hoyrat F1, Sprint F1, and Joki F1 hybrids demonstrated the most balanced profiles: optimal dry matter content, high organoleptic quality, low nitrate accumulation, and acceptable levels of sugars and vitamin C. These traits support their classification as promising varieties from the perspective of comprehensive quality and safety assessment.

The analysis of the cost structure for growing cucumber hybrids shows that the main financial burden is associated with maintaining intensive cultivation technologies and ensuring optimal microclimatic conditions in greenhouses. The largest share of production costs is attributed to heating gas (33.8%) and fertilizers (29.6%).

The significant share of heating (gas) costs is due to the need to maintain a stable temperature regime during the cold season, especially at the beginning of the production cycle when thermal load is at its peak. It is worth noting that, under typical conditions, greenhouse heating costs can range from 30% to 70% of total production costs, depending on climate conditions, greenhouse type, and technologies used. In cold regions, such as northern China, heating can account for more than 40% of greenhouse operating expenses. In countries with temperate climates, such as Canada, the UK, and the

Netherlands, heating costs can reach up to 85% of total operating expenses [43–45]. However, in this study, due to favorable energy market conditions and relatively low gas prices, the share of this cost item was reduced to 31.5%, which significantly improved overall production efficiency.

The high cost of fertilizers is explained by the need for regular and balanced plant nutrition throughout the entire growing season, particularly in hydroponic cultivation systems, where specialized and costly mineral nutrient solutions are used [46, 47].

The next most significant cost item is electricity (20.0%), which is used for lighting systems, ventilation, automation, pumping equipment, and other essential greenhouse systems. The share of consumables (11.7%) is also notable and is explained by the fact that most of the materials used (peat substrates, polyethylene film, drip tapes, containers, etc.) are imported and therefore sensitive to currency fluctuations and logistics costs. The least expensive items are seeds and water-3.0% and 1.8%, respectively. The low water costs are due to the use of water-saving drip irrigation technology [48–50]. Although seeds represent a small portion of the cost structure, their cost still impacts overall production expenses, especially when using modern hybrids with high yield potential, resistance, and market quality.

The production cost of the studied cucumber hybrids was within a narrow range-between \$8.87 and \$8.97 per square meter. This minor variation is mainly explained by differences in seed prices, as the agronomic technology was identical for all variants.

The key factors influencing revenue from product sales included the yield rate and consistency, as well as the market price for fresh cucumbers during the harvesting period. The highest revenue was generated by the hybrid Melen F1-\$41.53/m<sup>2</sup>, slightly ahead of Sprint F1 (\$41.48/m<sup>2</sup>) and Joki F1 (\$41.02/m<sup>2</sup>). The lowest revenue was recorded for the Magnum F1 hybrid-\$35.12/m<sup>2</sup>, which was attributed to less favorable fruiting dynamics or the unfortunate timing of the main harvest coinciding with a market price drop.

The calculated profit varied slightly, with the highest values recorded for the Sprint F1 (\$32.58/m<sup>2</sup>), Melen F1 (\$32.55/m<sup>2</sup>), and Joki F1 (\$32.10/m<sup>2</sup>) hybrids, indicating the high efficiency of these cultivars under identical cultivation costs. Their advantage was due to a higher early yield sold during peak market prices, significantly increasing overall profitability. The lowest profit was recorded for the Magnum F1 hybrid-\$26.25/m<sup>2</sup>, indicating a less favorable combination of fruiting rate and market pricing during the sales period.

The profitability of production across all studied hybrids was high-ranging from 74.7% to 78.5%. The leading hybrids in this regard were Sprint F1 (78.5%), Melen F1 (78.4%), and Joki F1 (78.3%). The Hoyrat F1 hybrid also demonstrated a substantial profitability level (78.1%), which, despite lower productivity and overall efficiency, achieved a competitive result due to the lowest seed cost. This significantly reduced the cost of production, allowing profitability comparable to the leading cultivars. The lowest profitability was shown by the Magnum F1 (74.7%) and Infinity F1 (75.8%) hybrids, which nevertheless still reflect high economic efficiency in cultivation.

Thus, under comparable cultivation costs, the main factors influencing economic performance were the dynamics of fruiting and the timing of market entry. The volume of early yield proved to be particularly important, as it accounted for a significant share of revenue due to sales at peak seasonal prices. Hybrids with profitability exceeding the standard sample were characterized by a high level of early yield. Conversely, hybrids with profitability below the standard showed reduced values of both early and total yield. This confirms a direct correlation between the level of early yield and the economic efficiency of production, highlighting its importance as one of the key criteria when selecting a hybrid for commercial cultivation.

## Conclusion

The results of the conducted study demonstrated that when selecting hybrids for greenhouse cultivation under conditions of limited solar radiation (without supplemental lighting in February–March), it is advisable to prioritize varieties that combine adaptability to agro-climatic conditions, high yield due to a balance between fruit weight and number, as well as good quality and product safety.

Among the studied hybrids, only Sprint F1 and Multistar F1 St met the declared timelines for the onset of fruiting. The remaining hybrids lagged behind the stated schedules, primarily due to insufficient sunlight and a consequent reduction in

photosynthetic activity. In terms of yield, the best-performing hybrids were Sprint F1 - thanks to a combination of high fruit count and weight-along with Melen F1, Hoyrat F1, Joki F1, and Kirton F1, mainly due to the increased average fruit weight.

Agrochemical analysis showed that Melen F1, Hoyrat F1, Sprint F1, Joki F1, and Kirton F1 have elevated levels of dry matter and a reduced tendency to accumulate nitrates, indicating high market value and environmental safety. On the other hand, Magnum F1 and Infinity F1 had significantly lower dry matter content and higher nitrate levels, which reduce their desirability. The organoleptic properties, as well as sugar and vitamin C content, in most hybrids remained at stable levels that meet the requirements of GOST 1726-85, confirming their suitability for fresh market consumption.

The cultivation of cucumber hybrids under intensive greenhouse technology demonstrated high economic efficiency. Favorable regional energy market conditions significantly reduced specific costs for maintaining agronomic standards and optimal microclimates, which positively impacted production costs. The cost of cultivation for all studied hybrids remained within a stable range (\$8.87-\$8.97/m<sup>2</sup>), indicating unified technological approaches and effective cost control. Differences in final economic outcomes were mainly due to market prices during the sales period and the fruiting dynamics of specific hybrids. The highest profitability levels were recorded for the early-maturing hybrids Sprint F1, Melen F1, Joki F1, and Hoyrat F1, which highlights their strong commercial appeal and suitability for use in intensive vegetable production technologies. These hybrids demonstrate an optimal combination of high yield, marketable quality, and environmental safety, while consistently ensuring a high level of profitability. This combination of traits makes them an ideal choice both for industrial vegetable farming and for small-scale producers focused on generating stable profits from the sale of high-quality fresh produce.

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## Author's Contributions

Gulsim Zikiryevna Sauytbayeva: Development of the research concept, formulation of research goals and objectives, scientific supervision, coordination of the study, and manuscript editing.

Rakhym Iskendirovich Kudiyarov: Development of the experimental methodology and design, organization of studies on growing cucumber hybrids under greenhouse conditions.

Laura Anuarovna Tokhetova: Conducting phenological observations and biometric studies of plants, determination of productivity indicators, and yield calculation.

Ibadulla Aigalievich Tautenov: Investigation of the physiological state of plants, identification of growth and development disorders, monitoring of diseases and pests, and development of measures for their prevention and control, preparation of the first draft of the manuscript.

Galina Evgenievna Dyamurshayeva: Conducting experimental studies, phytomonitoring of microclimate parameters, control of irrigation and nutrient solution supply regimes, and collection of experimental data. Corresponding author.

Elina Bakhtiyarovna Dyamurshayeva: Statistical processing and analysis of experimental data (ANOVA), interpretation of research results.

Abyzbekova Gulmira Mynbayeva: Biochemical analysis of fruit quality, including determination of soluble solids, sugars, ascorbic acid, and nitrate ion content, as well as evaluation of organoleptic characteristics of the products.

Nurlan Zhetkergenovich Urazbayev: Economic analysis of the efficiency of cucumber hybrid cultivation, calculation of production costs, cost price, revenue, profit, and profitability level.

All authors participated in the discussion of the research results and approved the final version of the manuscript.

## Ethics

This research was conducted in full compliance with established principles of scientific ethics. No human or animal subjects were involved. The authors declare no conflicts of interest.

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