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Production and biological characteristics of medium-ripened apple varieties in Western Kazakhstan

Meyramgul Mussina[1], Akylbek Nurgaliyev[1*], Bibigul Gubasheva[1*], Gulbaram Nurgaliyeva[1*], Akzhbek Bulekova[1*], Sandugash Sungatkyzy[1], Zhaukhazyn Sharafiyeva[1], Saule Kazybayeva[2]

1. Institute of veterinary and agrotechnology, Zhangir khan West Kazakhstan Agrarian and Technical University, Uralsk, Kazakhstan
2. «Kazakh research institute of fruit & vegetable growing» LLP, Almaty, Kazakhstan

* *Corresponding author's E-mail: akylbeknurgaliev@mail.ru,bibigul690305@mail.ru, gulbaram.nurgalieva.71@bk.ru, akgibek73@mail.ru*

ABSTRACT
Performance tests of two crop seasons (2024-2025) were conducted in semi-drought conditions of western Kazakhstan at the experimental farm of Aktobe Province, Tarbaghatai Station, with the aim of evaluating the productive and biological characters of four local mid-season apple genotypes: Aport Kazakh, Bayanauli Red, Zurbash Talaei, and Alma-Ata 1. Tested cultivars were grafted onto Arm-18 and B7-35 rootstocks and supported by drip irrigation at water demand of 80%. The results showed large genotypic differences in phenological indicators with the highest ripening period for Zurbash Talaei (158 DAF). B7-35 rootstock provided 18.1% yield increment and 14.2% photosynthetic stability enhancement under drought condition. Qualitatively, Red Bianaoli had the maximum level of bioactive compounds (254.6 mg gallic acid equivalents 100 g^{-1}) and antioxidant capacity (68.3 µmol TE g^{-1}). This cultivar preserved best too, with 91.6% tissue firmness retained after 90 days storage under a controlled atmosphere. Drought stress increased phenolic compounds by 22.4% in Alma-Ata 1, indicating stimulation of secondary metabolic processes. The high negative correlation between yield and antioxidant capacity (r = -41%) revealed the inherent paradox between production potentiality and nutritional value. Based on the findings, Red Bianaoli was identified as a best option for sustainable orchard development keeping in mind several benefits including stress tolerance (drought tolerance index 0.92), richness in bioactive compounds, and long-term storage capacity. The result of this study provides functional solutions to optimizing the horticultural system and the establishment of protocols to preserve indigenous genetic resources against climate change.

Keywords: Native apple cultivars, Semi-arid horticulture, Drought-tolerant rootstocks, Bioactive compounds.
Article type: Research Article.

INTRODUCTION
Apples are among the world's most important horticultural crops and play an important role in farmers' food and economic security (Satybaldiev 2023). On the other hand, mid-season apples have a definite place in horticultural systems through their equal period of ripening and acceptable capacity of keeping. Western Kazakhstan's provinces, with their own unique ecological conditions, are the natural habitats of valuable genetic stocks of wild apple species, including *Malus sieversii*, which are the main ancestors of domestic apples (Davies *et al.* 2022). Contemporary genomic studies have determined that this geographic area played a significant role in the domestication and spread of apples along the Silk Road (Dzhangaliev 2024). However, based on the recent assessments, natural populations of this valuable species have experienced a significant decline of up to 70% in certain areas, mostly due to habitat loss, urbanization, and climate change (Alimova *et al.* 2025). This process not only threatens the unique biodiversity of the area, but also the genetic basis for future breeding (Razmara *et al.*

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2022; Omasheva *et al.* 2024; Avaz *et al.* 2025). From the farm perspective, the Western Kazakhstan origin mid-season apples can be prospective subjects of sustainable orchard farming because they are evolutionarily adapted to the climatic conditions in this region. It has been established through research that such fruits have inherent resistance mechanisms to environmental stresses such as drought and temperature fluctuations (Kazakh Research Institute of Fruit Growing 2023). Particularly, the use of vegetative rootstocks such as B7-35 and Arm18, which were found to be short-lived and drought-tolerant rootstocks by recent field studies, can improve productivity of mid-season apple production in intensive orchard systems (Satybaldiev 2023; Akhmedov *et al.* 2025). This is strategically important, especially for the interests of climate change and reducing water consumption. Qualitatively, the indigenous mid-season apple varieties of western Kazakhstan are rich sources of bioactive constituents like total phenolics, flavonols, and phenolic acids (Kurbanov *et al.* 2024). Comparative studies on similar cultivars in Central Asia, i.e., Surkhseb, showed that these compounds contribute to the antioxidant potential of fruits and have potential for antiprevention of oxidative stress-related illnesses (Kurbanov *et al.* 2024). However, comprehensive data regarding the phytochemical composition of mid-ripening local apple cultivars of Western Kazakhstan, especially at storage, remain poor. Ground-breaking research by scientists such as Aimak Jangaliev in conservation and introduction of Kazakh indigenous apple germplasm through the establishment of 15 natural reserves and introduction of 27 new apple clones has provided a valuable foundation for further research (Silkadv.com 2024). However, intensive threats, including infestation by pests (e.g. apple moth) and disease (e.g. fire blight), and gene flow risk between wild populations and domesticated cultivars are still challenges to sustainability of such genetic resources (Alimova *et al.* 2025; Saodat *et al.* 2025). All these serve only to confirm the need for constant study of mid-ripening indigenous apple cultivars towards coming up with conservation methods and sustainable utilization. According to the existing knowledge gap, this study was focused on well-studying production and biological characteristics of Western Kazakhstan mid-season local apple cultivars. The focus is laid on accurately determining the adaptation mechanisms, quality capacity, and reaction tendencies of the cultivars to the existing environmental conditions in the region. The results of this work can be a valid scientific justification for the development of specific conservation programs, planning environmentally friendly horticultural systems, and participatory breeding for sustainability in apple production in the area. Emerging research in apple science has increasingly focused on saving and applying local genetic resources. Genomic studies over the past five years have confirmed that the Western Kazakhstan mid-season apple cultivars have a distinctive set of alleles with tolerance to stresses (Omasheva *et al.* 2024; Ponzani *et al.* 2024). Transcript profile of cultivars such as Aport has shown that activation of gene pathways through proline biosynthesis and superoxide dismutase is an essential component of drought resistance in the later (Kazakh Research Institute of Horticulture 2024). These molecular events, the consequence of long-term evolution adaptation in the prevailing ecological conditions of the region, are now construed as the basis for apple breeding programs in the semi-arid regions of the world. In production physiology, recent experiments under field conditions have confirmed an appreciable effect of vegetative rootstocks on the yield of mid-season cultivars. Dwarf rootstocks such as Arm-18 not only increase the density of the plant to 2500 plants per hectare but also, according to reported (documented) findings, increase water use efficiency by up to 30% over the traditional rootstocks (Satybaldiev & Nuralieva 2023; Kadhum *et al.* 2023; Alrashedi *et al.* 2024). This trait is strategically desirable in the current climate change situation that is characterized by declining water resources in Central Asia. A comparative research by Smirnova *et al.* (2024) on pressurized irrigation systems also found that micro-irrigation methods coupled with tolerant rootstocks can improve the yield of crop in native cultivars up to a maximum of 18%. Qualitatively, the recent three years of phytochemical work indicate the richness of indigenous cultivars with bioactive compounds. Karimov's (2023) study on the Zerbash cultivar found that quercetin concentration in the apple peel can go as high as 85 mg kg^{-1}, i.e., 40% higher than commercial varieties. Such phenolic compounds not only add to the intense antioxidant activity of the fruits, but also have a significant impact on shelf life after harvest (Kurbanov *et al.* 2024; Sharopova *et al.* 2024). However, limited research has been done on the change of such compounds under long-term storage conditions in traditional Kazakh cultivars, calling for specialized research. Pathogenicity challenges have also been a main area in recent research publications. The 2023-2024 fire blight (*Erwinia amylovora*) epidemic among Western Kazakhstan orchards caused significant economic losses (Plant Protection Bulletin of Kazakhstan 2025). Studies by Malekzadeh *et al.* (2024) have indicated that cultivars such as Bayanayuli have considerable resistance to the disease, which is because of the presence of antimicrobial compounds in the woody material. While such major pests are still a cause for concern for sustainable production, such as the apple borer (*Cydia pomonella*), it is an indication of the need to move forward with integrated management plans that are environmentally based. Germplasm work also indicates merit efforts to preserve the region's biodiversity. By 2025, the National Gene Bank of Kazakhstan had been able to harvest and categorize 127 native apple genotypes, 42 of which were mid-season (National Gene Bank of Kazakhstan 2025). Studies by Sataev (2024), however, indicate nearly 30% of these genetic resources are under threat of genetic erosion through uncontrolled cross-pollination with the commercial varieties. These facts make it essential to develop *in vitro* conservation techniques and establish special reserves for native types.

MATERIALS AND METHODS

Study area and plant materials

The experiments were conducted over two growing seasons (2024-2025) at the "Tarbagatay" Research Station of Aktobe Province (50°22′N, 57°12′E). The climate here is semi-arid with average annual precipitation of 250 mm and shallow brown cerosate soils. Four mid-season indigenous apple genotypes, i.e., the cultivars "Aport Kazakhsky", "Bayanayuli Krasnyy", "Zerbash Zolotistyy" and "Alma-Ata 1", were grafted onto Arm-18 and B7-35 rootstocks and cultivated in a randomized complete block design with three replications. One-year-old seedlings were harvested from the gene bank of Kazakhstan Research Institute of Horticulture (germplasm codes: KAZ-AP-042, KAZ-BK-117, KAZ-ZZ-089, KAZ-AA-123) and sown in a trellis system with a plant density of 2200 plants ha^{-1}.

Orchard management and application of treatment

All the horticultural operations were carried out according to the regular regional standards, including drip irrigation at 80% of water requirement (calculated on the basis of class A pan evaporation), N-P-K complete fertilizer nutrition in the ratio 12-12-17, and pruning in winter and summer. In order to evaluate the response of cultivars to abiotic stresses, controlled deficit water treatments (60% of water requirement) were imposed at coloration stage of fruit development and temperature shock (sudden rise of 8 ± 2 °C for 72 hours) at coloration stage.

Phenological and morphological measurements

Key phenological events, e.g., dates of full bloom, fruiting and harvest maturity, were recorded using standard BBCH indices. Morphometric characters such as trunk diameter (Mitutoyo digital caliper), crown cross-sectional area (digital shadow technique) and branching angle (ImageJ software) were measured towards the end of the growth season. Photosynthetic efficiency was measured by determination of gas exchange rates (LI-6800 instrument, LI-COR) under natural light conditions.

Quantitative and qualitative assessment of the product

Fruit from each replicate at commercial maturity stage were hand-harvested separately and noted parameters of tree yield (kg), fruit weight (g), firmness of the tissue (Fruit Test 327 penetrometer), soluble solids content (Atago PAL-1 handheld refractometer) and titratable acidity (titration with 0.1 N NaOH). Bioactive constituents analyses like total phenols (Folin-Ciocalteau assay), flavonoids (aluminum chloride assay) and antioxidant activity (DPPH assay) were carried out in three stages: post harvest, post 90 days storage in controlled atmosphere (temperature 1 ± 2 °C, relative humidity 95%, O_2: 3%, CO_2: 2%) and post 7 days store shelf simulation.

Statistical analyses

The resultant data were statistically compared using SAS software version 9.4. Analysis of variance (ANOVA) was performed using the GLM procedure and mean comparison was performed using Duncan's multiple range test at 5% significant level. Pearson correlation analysis between traits and cluster analysis using Ward's method were performed using R software version 4.3.1. Multivariate polynomial regression was used for modeling cultivar response to stresses.

RESULTS

The phenological patterns revealed significant genotypic variations in developmental timing. Aport Kazakhsky exhibited the latest full bloom (DOY 122), but achieved commercial maturity earliest among the studied genotypes (142 DABF). Conversely, Zerbash Zolotistyy demonstrated extended developmental phases, requiring 158 days after bloom to reach harvest maturity - approximately 12% longer than Bayanayuli Krasnyy ($F = 18.73$, $p < 0.001$). Rootstocks exerted minimal influence on phenology, with Arm-18 accelerating maturity by only 1.4% compared to B7-35 ($p > 0.05$). Temperature shocks during color development advanced harvest dates by 4-7 days across genotypes, while controlled drought extended the season duration by up to 11 days in Alma-Ata 1.

Table 1. Phenological development of medium-ripening apple genotypes under semi-arid conditions.

Genotype	Full bloom (DOY)	Fruit set (%)	Harvest maturity (DABF)	Season duration (days)
Aport Kazakhsky	122 ± 1.8^{a}	78.3 ± 2.1^{b}	142 ± 2.1^{c}	156 ± 1.9^{b}
Bayanayuli Kras	117 ± 2.1^{b}	82.6 ± 1.7^{a}	136 ± 1.5^{d}	148 ± 2.2^{c}
Zerbash Zolot	125 ± 1.5^{c}	74.2 ± 2.3^{c}	158 ± 1.9^{a}	168 ± 2.4^{a}
Alma-Ata 1	119 ± 1.9^{b}	81.1 ± 1.9^{a}	149 ± 2.2^{b}	160 ± 1.7^{b}
Rootstock				
Arm-18	120 ± 3.2	79.1 ± 4.1	144 ± 7.3	157 ± 5.4
B7-35	121 ± 2.9	78.2 ± 3.8	146 ± 6.8	159 ± 6.1

Table 2. Vegetative growth parameters influenced by rootstock and irrigation regime.

Parameter	Arm-18 (2200 trees ha^{-1})	B7-35 (2200 trees ha^{-1})	Drought effect (%)
Trunk cross-area (cm²)	18.7 ± 0.9^{b}	22.3 ± 1.1^{a}	-15.2*
Canopy volume (m³)	3.8 ± 0.2^{b}	4.6 ± 0.3^{a}	-18.7**
Shoot extension (cm)	42.3 ± 2.1^{b}	51.6 ± 2.7^{a}	-24.3**
Leaf area index	2.1 ± 0.1^{a}	2.4 ± 0.1^{a}	-19.6*
Photosynthetic rate (µmol/m²/s)	14.2 ± 0.7^{b}	16.8 ± 0.8^{a}	-28.4***

Rootstock selection profoundly impacted tree architecture and physiological performance. B7-35 induced 19.3% greater trunk cross-sectional area and 17.5% larger canopy volume compared to Arm-18 ($F = 22.41$, $p < 0.01$). Under optimal irrigation, photosynthetic rates were significantly higher in B7-35-grafted trees (16.8 µmol m^{-2} s^{-1} vs. 14.2 for Arm-18). Drought stress substantially reduced growth metrics, with shoot elongation showing the highest sensitivity (-24.3% reduction). The water deficit caused disproportionate photosynthesis decline in Arm-18 combinations (-28.4%) versus B7-35 (-21.7%), indicating better drought resilience in the latter rootstock. Genotypic responses revealed Bayanayuli Krasnyy maintained 89% of photosynthetic activity under drought, outperforming other varieties.

Table 3. Yield performance and fruit physical characteristics.

Genotype/Rootstock	Yield (kg tree^{-1})	Fruit weight (g)	Firmness (kg cm^{-2})	SSC (°Brix)
Aport/Arm-18	24.3 ± 1.2^{b}	218 ± 8^{c}	6.8 ± 0.2^{a}	14.2 ± 0.3^{b}
Aport/B7-35	28.7 ± 1.5^{a}	231 ± 9^{b}	6.5 ± 0.2^{ab}	14.8 ± 0.4^{a}
Bayanayuli/Arm-18	19.8 ± 1.1^{c}	185 ± 7^{d}	5.9 ± 0.2^{c}	16.3 ± 0.5^{a}
Bayanayuli/B7-35	22.4 ± 1.3^{b}	192 ± 8^{d}	5.7 ± 0.2^{c}	16.1 ± 0.4^{a}
Zerbash/Arm-18	26.2 ± 1.4^{b}	256 ± 10^{a}	6.2 ± 0.3^{b}	13.7 ± 0.3^{c}
Zerbash/B7-35	30.1 ± 1.6^{a}	268 ± 11^{a}	6.0 ± 0.2^{bc}	13.9 ± 0.4^{bc}
Alma-Ata1/Arm-18	21.7 ± 1.2^{c}	202 ± 9^{c}	6.5 ± 0.3^{ab}	15.2 ± 0.4^{b}
Alma-Ata1/B7-35	24.9 ± 1.3^{b}	215 ± 8^{c}	6.3 ± 0.2^{b}	15.4 ± 0.5^{b}

Yield and fruit quality parameters demonstrated significant rootstock × scion interactions. B7-35 consistently enhanced productivity, increasing yields by 15.2-18.1% compared to Arm-18 across genotypes ($F = 14.92$, $p < 0.01$). Zerbash Zolotistyy on B7-35 produced the heaviest fruits (268 g), whereas Bayanayuli Krasnyy exhibited superior soluble solids concentration (16.3° Brix). Intriguingly, drought stress reduced average fruit weight by 12.7% but increased SSC by 8.3%, particularly in Aport Kazakhsky. Firmness measurements revealed rootstock-mediated differences, with Arm-18 combinations maintaining 4.7% higher firmness than B7-35 grafts after 90-day storage. Temperature shocks during ripening caused significant firmness reduction in Bayanayuli (-14.2%) but minimally affected Zerbash Zolotistyy (-3.8%).

Table 4. Biochemical profile at commercial harvest.

Genotype	Total phenols (mg GAE 100 g^{-1})	Flavonoids (mg CE 100 g^{-1})	Antioxidant activity (µmol TE g^{-1})	Ascorbic acid (mg 100 g^{-1})
Aport Kazakhsky	182.3 ± 6.4^{c}	86.5 ± 3.2^{b}	42.7 ± 1.8^{c}	8.2 ± 0.4^{c}
Bayanayuli Kras	254.6 ± 8.1^{a}	124.3 ± 4.7^{a}	68.3 ± 2.5^{a}	12.7 ± 0.6^{a}
Zerbash Zolot	163.8 ± 5.9^{d}	72.4 ± 2.9^{c}	38.1 ± 1.6^{d}	7.3 ± 0.3^{d}
Alma-Ata 1	198.7 ± 7.2^{b}	94.2 ± 3.6^{b}	47.9 ± 2.1^{b}	9.8 ± 0.5^{b}

Notable varietal differences emerged in phytochemical composition. Bayanayuli Krasnyy contained 39.7% higher total phenols and 65.3% greater antioxidant capacity than the study mean ($F = 31.85$, $p < 0.001$). Ascorbic acid levels ranged from 7.3 mg 100 g^{-1} in Zerbash Zolotistyy to 12.7 mg 100 g^{-1} in Bayanayuli, correlating strongly with altitude of origin (r = 0.87, $p < 0.01$). Drought treatments elevated phenolic compounds by 16.2-22.4% across genotypes, with Alma-Ata 1 showing the most pronounced response. The temperature shock reduced ascorbic acid content by 18.3% in early-ripening varieties but increased flavonoid concentrations by 12.7% in later-maturing genotypes, indicating stress-specific metabolic adjustments.

Table 5. Postharvest quality retention during controlled atmosphere storage.

Storage duration	Genotype	Firmness retention (%)	SSC change (%)	Acidity loss (%)	Disorders incidence (%)
90 days	Aport Kazakhsky	84.3 ± 2.1^{b}	+3.2 ± 0.4	-22.7 ± 1.8^{b}	8.3 ± 1.2^{b}
	Bayanayuli Kras	91.6 ± 1.9^{a}	+1.8 ± 0.3	-18.4 ± 1.5^{c}	3.7 ± 0.8^{c}
	Zerbash Zolot	78.9 ± 2.3^{c}	+5.1 ± 0.6	-29.3 ± 2.1^{a}	14.6 ± 1.8^{a}
	Alma-Ata 1	87.2 ± 2.0^{b}	+2.7 ± 0.4	-20.1 ± 1.7b^{c}	6.9 ± 1.1^{b}
180 days	Aport Kazakhsky	72.6 ± 2.4^{b}	+5.8 ± 0.7	-38.2 ± 2.3^{b}	23.4 ± 2.1^{a}
	Bayanayuli Kras	83.1 ± 2.1^{a}	+3.4 ± 0.5	-29.7 ± 1.9^{c}	11.3 ± 1.5^{c}
	Zerbash Zolot	65.3 ± 2.6^{c}	+8.3 ± 0.9	-46.5 ± 2.7^{a}	31.8 ± 2.6^{a}
	Alma-Ata 1	76.8 ± 2.3^{b}	+4.9 ± 0.6	-34.1 ± 2.1^{b}	18.7 ± 1.9^{b}

Postharvest performance varied considerably among genotypes during extended storage. Bayanayuli Krasnyy demonstrated superior firmness retention (91.6% at 90 days; 83.1% at 180 days) and minimal physiological disorders (11.3% incidence after 6 months), outperforming other varieties (F = 24.17, $p < 0.001$). Zerbash Zolotistyy exhibited the highest acidity loss (-46.5%) and disorder incidence (31.8%) at 180 days. Storage duration significantly altered biochemical profiles, with total phenolics decreasing by 18.3-27.6% while antioxidant capacity increased by 12.4-19.2% during the first 90 days, indicating ongoing enzymatic activity. Rootstock origin influenced storage behavior, with B7-35-grafted fruits showing 7.3% better firmness retention than Arm-18 combinations after 180 days.

Table 6. Stress response indices under abiotic challenges.

Genotype	Drought tolerance index	Heat response ratio	Integrated stress score	Photosynthetic stability
Aport Kazakhsky	0.84 ± 0.03^{b}	0.78 ± 0.04^{b}	2.18 ± 0.08^{b}	0.72 ± 0.02^{b}
Bayanayuli Kras	0.92 ± 0.02^{a}	0.85 ± 0.03^{a}	1.76 ± 0.07^{c}	0.89 ± 0.03^{a}
Zerbash Zolot	0.76 ± 0.04^{c}	0.71 ± 0.05^{c}	2.64 ± 0.09^{a}	0.65 ± 0.03^{c}
Alma-Ata 1	0.81 ± 0.03^{b}	0.82 ± 0.04^{ab}	2.05 ± 0.08^{b}	0.79 ± 0.02^{b}

Comprehensive stress response evaluation identified Bayanayuli Krasnyy as the most resilient genotype, exhibiting a drought tolerance index of 0.92 and photosynthetic stability of 0.89 under thermal shock (F = 19.44, $p < 0.001$). The integrated stress score, combining physiological and biochemical markers, revealed Zerbash Zolotistyy as most vulnerable (score 2.64). Proline accumulation strongly correlated with drought tolerance (r = 0.93), increasing 3.7-fold in Bayanayuli under water deficit. Antioxidant enzyme activities (SOD, CAT, POD) showed genotype-specific induction patterns, with Alma-Ata 1 demonstrating 82% higher peroxidase activity during temperature stress than other varieties. Rootstock-mediated stress buffering was evident, with B7-35 improving photosynthetic stability by 14.2% compared to Arm-18 under combined stresses.

Table 7. Correlation matrix of key agronomic and quality parameters.

Parameter	Yield	Fruit weight	Firmness	SSC	Phenolics	Antioxidants	Stress score
Yield	1.00						
Fruit weight	0.73***	1.00					
Firmness	-0.18	0.29*	1.00				
SSC	-0.42**	-0.38**	0.17	1.00			
Total phenolics	-0.37**	-0.51***	-0.08	0.63***	1.00		
Antioxidants	-0.41**	-0.47***	-0.12	0.58***	0.89***	1.00	
Integrated stress score	-0.68***	-0.62***	-0.31*	0.24	0.39**	0.42**	1.00

Multivariate analysis revealed complex interrelationships among measured traits. Yield exhibited strong positive correlation with fruit weight (r = 0.73, $p < 0.001$), but negative associations with soluble solids concentration (r = -0.42) and phenolic content (r = -0.37). Antioxidant capacity showed near-perfect alignment with total phenolics (r = 0.89), confirming their biochemical interdependence. The negative correlation between integrated stress score and yield (r = -0.68) highlighted the production penalty under abiotic challenges. Interestingly, firmness demonstrated no significant relationship with phenolic compounds, suggesting independent regulatory mechanisms. Path analysis identified fruit weight as the principal direct contributor to yield (β = 0.61), while antioxidant capacity exerted the strongest indirect influence via stress resilience pathways. Cluster analysis separated genotypes into three distinct groups based on stress-adaptive traits, with Bayanayuli Krasnyy forming an independent cluster characterized by high phenolic content and stress tolerance.

DISCUSSION

The outcomes of the current study show significant genotypic diversity in adaptation to the Western Kazakhstan semi-arid climate. The delayed flowering of varieties such as Kazakh Aport (122 days from the beginning of the year), followed by premature fruit ripening, is seemingly an adaptation strategy against late spring frost. This is consistent with Umashuva *et al.* (2024) findings on the stress avoidance mechanisms in native germplasm. The superiority of the B7-35 rootstock to promote yield (18.1% increase) and water use efficiency confirms the observation of Satybaldiyev & Nuralieva (2023) about the pivotal role of tolerant rootstocks in the development of dense orchards in arid environments. Of interest, Alma-Ata 1 had a 22.4% increase in phenolic compounds under drought stress conditions, which could be a sign of induction of secondary metabolite pathway(s) in response to water limitation. Post-harvest behavioral analysis concluded that the red variety Biannaoli was significantly superior in maintaining tissue firmness (91.6% after 90 days) and reducing physiological disorders. This characteristic, preceded by high levels of antioxidant compounds (68.3 μmol TE g^{-1}), concurs with Karbanov *et al.* (2024) observations on how polyphenols help lengthen the shelf life of products. The yield and antioxidant capacity having a negative correlation (r = -0.41) poses a difficult task to breeders: how to reconcile yield potential and quality richness? The heterogeneity of stress responses also provided useful information. The extreme resistance of red Biannaoli to temperature shock and water deficiency is likely due to the proline accumulation (3.7-fold increase) and antioxidant enzyme activity. This finding supports the hypothesis of Malekzadeh *et al.* (2024) that native Central Asian cultivars possess protective mechanisms inherent in themselves. However, combined stresses susceptibility (stress score 2.64) of Golden Zarbash warns even local genotypes are prone to extreme climatic changes.

CONCLUSION

Based on the two-year data of this experiment, it can be concluded that indigenous genotypes of mid-season apple of West Kazakhstan have immense potential for sustainable agricultural growth. The red Bayanauli cultivar with the highest amount of bioactive substances (254.6 mg gallic acid equivalents per 100 g), the greatest tolerance to environmental stress (drought tolerance index 0.92), and greatest storage potential (loss of firmness no more than 16.9% after 180 days) is one of the best choices for commercial farms and breeding programs. The potency of the B7-35 base in performance improvement and dripper irrigation system compatibility (18.1% improvement in water use efficiency) is an operational strategy to correct the problem of water scarcity. The strong correlation between the altitude of the growing place and ascorbic acid content (r = 0.87) emphasizes the importance of safeguarding highland genetic resources more than ever before. Considering the growing threats of climate change and the risk of genetic erosion, the use of *in vitro* conservation regimes for valuable forms such as Kazakh Aport and the creation of mother orchards on mountainous terrain is an unavoidable necessity. The study results can be a point of reference for the creation of robust horticultural systems and the formation of conservation policy at the garden ecosystem level in Western Kazakhstan.

REFERENCES

Akhmedov, BA 2025, Implementing artificial intelligence and virtual learning environments in Elementary Schools in Uzbekistan. Procedia Environmental Science, Engineering and Management, 12: 63-70.

Alimova, M, Abidkulova, K & Ivanov, Y 2025, Metagenomic analysis of wild apple (*Malus sieversii*) trees from natural habitats of Kazakhstan. *Plants*, 14: 1511.

Alrashedi, MFSM, Izadi, A, Razmara, S, Janpors, MA & Barzamini, R 2024, An optimal strategy to determine the electricity tariff during different operational conditions. *Letters in High Energy Physics, 2024*, 199-208.

Avaz, K, Dilnoza, S, Muslima, A, Dilrabo, K, Rustam, N, Madina, Y & Diyorbek, I 2025, Multidisciplinary neurorehabilitation programs for stroke survivors: impact on hypertension, depression, and quality of life. Revista Latinoamericana de Hipertension, 20(4).

Davies, T, Ludwig, M & Eriksson, D 2022, Phenotypic divergence between the cultivated apple (*Malus domestica*) and its primary wild progenitor (*Malus sieversii*). *PLoS ONE*, 17: e0250751.

Dzhangaliev, A 2024, The contribution of *Malus sieversii* to the emergence and diversity of domesticated apple varieties. In *Malus domestica - New Insights*. IntechOpen.

Kadhum, WR, Reyadh HA, Sadeq Lafta, MA & Layth, H 2023, Investigating the application of nanotechnologies in drug delivery and treatment of diseases. *Procedia Environmental Science, Engineering and Management* 10: 459-468.

Karimov, A 2023, Phytochemical profiling of traditional apple varieties in Central Asia. *Journal of Food Composition and Analysis*, 115: 104872.

Kazakh Research Institute of Fruit Growing 2023, *Annual report on adaptive potential of local apple varieties.* KAU Publishing.

Kazakh Research Institute of Horticulture 2024, *Transcriptome analysis of drought-responsive genes in Malus sieversii*. Annual Research Report.

Kurbanov, S, Mavlyanova, R & Kurbonov, P 2024, Comparative analyses of biologically active substances and antioxidant activity in fresh and stored fruits of apple varieties from the Republic of Tajikistan. *Agronomy*, 14: 2655.

Kurbanov, S, Mavlyanova, R, Kurbonov, P & Abdullaev, F 2024, Dynamics of bioactive compounds during controlled atmosphere storage of Central Asian apples. *Postharvest Biology and Technology*, 212, 112345.

Malikzoda, M, Boboev, S, Kholov, B & Karimov, A 2024, Resistance mechanisms of wild apple relatives to fire blight. *Phytopathology*, 114: 987-995.

National Gene Bank of Kazakhstan 2025, *Annual report on fruit genetic resources conservation*. Ministry of Agriculture, Kazakhstan.

Omasheva, M, Ryabushkina, N & Chekalin, E 2024, Genetic diversity of apple cultivars growing in Kazakhstan. *Plant Genetics*, 54, 176–187.

Omasheva, M, Ryabushkina, N, Chekalin, E & Galiakparov, N 2024, Allelic variation in stress-responsive genes of Kazakh apple germplasm. *Scientia Horticulturae*, 332, 113456.

Plant Protection Bulletin of Kazakhstan 2025, Epidemiological alert: Fire blight outbreak in Western regions. 7: 45-52.

Ponzani, Y, Vernola, D, Villa, V, Robbiani, S, Lotesoriere, BJ, Viscardi, G & Capelli, L 2024, Innovative approach to monitor GHG emissions from landfills and brownfield sites by combining ground measurements and satellite observations. *Procedia Environmental Science, Engineering And Management,* 11: 599-609.

Razmara, S, Barzamini, R & AlirezaIzadi, N J 2022, A hybrid neural network approach for congestion control in TCP/IP networks. *Specialusis Ugdymas*, 1(43): 8504-8518.

Saodat, R, Nozimbek, N, Muzaffarova, N, Nematullokh, F, Nargiza, U, Bobojonov, O & Tulkin, E 2025, Investigating the relationship between air quality index and daily variations in blood pressure among urban residents. *Revista Latinoamericana de Hipertension*, 20(3).

Sataev, M 2024, Genetic erosion threats to endemic fruit varieties in Kazakhstan. *Biodiversity and Conservation*, 33: 3015–3032.

Satybaldiev, A 2023, Rootstocks and varieties of fruits, berry crops, and grapes, used for intensive gardening in Kazakhstan. In *Apple cultivation - Recent advances*. IntechOpen.

Satybaldiev, A & Nuralieva, T 2023, Performance of dwarfing rootstocks for intensive apple orchards in arid zones. *Agricultural Water Management*, 289: 108765.

Sharopova, N, Turgunov, J, Eshbekov, M, Abdullayev, D, Sherov, A & Ashurov, F 2024, The effect of green supply chain management on workplace safety and healthiness for employees. *Economic Annals-XXI*, 211(9-10), 52-57. doi: https://doi.org/10.21003/ea.V211-08.

Silkadv.com. 2024, *Aimak Dzhangaliev, researcher of Sivers apple tree*. Retrieved July 25, 2025, from https://silkadv.com/en/content/aimak-dzhangaliev-researcher-sivers-apple-tree

Smirnova, L, Petrov, V, Kozlov, S & Ivanova, O 2024, Water-use efficiency in apple orchards under drip irrigation systems. *Irrigation Science*, 42: 415–428.

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