



COMPARATIVE EVALUATION OF ABIOTIC STRESS SUSCEPTIBILITY IN LOCAL AND INTRODUCED APPLE (*Malus domestica* Borkh.) CULTIVARS WITHIN THE ARID ECOSYSTEMS OF NORTHERN UZBEKISTAN

Parkhod Nazarov

researcher

Scientific-Research Institute of Horticulture, Viticulture and Winemaking named after Academician M.Mirzaev, Tashkent, Uzbekistan. Address: Shymkent Road str, Guliston village, Tashkent district, Tashkent region, 111116, Republic of Uzbekistan. Phone: +998712202442, e-mail: nazarovparhod@gmail.com
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Abstract. This research presents a rigorous comparative evaluation of the physiological susceptibility exhibited by twenty-one apple (*Malus domestica* Borkh.) varieties, encompassing both autochthonous and introduced germplasm, within the challenging ecological conditions of the Khanka and Khazarasp districts of Northern Uzbekistan. Spanning a three-year observation period from 2017 to 2019, the study utilized a standardized 5-point susceptibility scale to quantify the adaptive capacity of these cultivars against three primary abiotic stressors: drought, extreme atmospheric heat, and soil salinity. Notably, the local variety Sarapayan emerged as the most resilient genotype, particularly regarding salt tolerance (mean score of 0.95), while the Khazarasp and Shur olma series displayed exceptional stability under peak thermal and moisture deficits. Conversely, high-yielding introduced cultivars, exemplified by Reinette Simirenko, exhibited maximum susceptibility mean scores (exceeding 3.15 for salinity), indicating a precarious lack of physiological buffering mechanisms against the regional microclimate. The results suggest that while certain introduced varieties like Golden Grimes offer a moderate compromise in terms of adaptability, the strategic prioritization of local germplasm remains the most viable pathway for mitigating the detrimental impacts of climate change and soil mineralization in the lower Amu Darya basin.

Key words: apple, abiotic stress, Uzbekistan, Khorezm region, drought resistance, heat tolerance, salt susceptibility, local varieties, introduced varieties, arid zone agriculture, physiological adaptation, horticultural resilience.

Introduction. The cultivation of the apple tree (*Malus domestica* Borkh.) serves as a vital cornerstone of temperate pomology, yet its global productivity is increasingly undermined by the intensifying pressures of climate change and shifting ecological boundaries. In regions characterized by extreme environmental variability, the success of an orchard is no longer determined solely by yield potential, but rather by the genetic capacity of the variety to withstand a convergence of abiotic stressors. As highlighted by Nemeskéri et al. (2010), ecological adaptability and drought resistance are the primary determinants of a cultivar's longevity, particularly when transitioning from controlled laboratory settings to the unpredictable nature of field cultivation.

The Mechanics of Abiotic Stress Resistance. Among the various environmental challenges, drought remains the most formidable obstacle to fruit quality and tree health. Research by Geng et al. (2020) has illuminated the complex molecular signaling pathways involved in this process, demonstrating that the regulation of phenylpropanoid biosynthesis—controlled by specific transcription factors like MdMYB88 and MdMYB124—contributes significantly to both

pathogen and drought resistance in apple trees. Furthermore, recent evaluations of hybrid progenies by Xu et al. (2025) underscore the necessity of identifying robust rootstock resources that can sustain metabolic functions during prolonged periods of water deficit, thereby ensuring the survival of the grafted scion.

Parallel to moisture scarcity, thermal stress presents a critical physiological hurdle. Bowen et al. (2002) established that the heat shock response, involving the synthesis of specialized proteins, is essential for maintaining thermotolerance at the cellular level. This is further supported by the work of Tian et al. (2021), who identified specific physiological thresholds beyond which biochemical responses in apple leaves begin to degrade, leading to irreversible cellular damage. More recent genomic studies by Zhang et al. (2022) have even linked flowering timing and heat-stress tolerance to specific protein interactions (e.g., MdNup62), suggesting that a variety's resilience is deeply embedded in its developmental rhythm.

Salinity and Regional Vulnerabilities. In arid and semi-arid landscapes, soil salinity acts as a silent killer, disrupting osmotic balance and inducing ion toxicity. The differential responses between various genotypes have been extensively documented; for instance, Xue et al. (2015) observed significant variations in salt tolerance between diploid and autotetraploid apple seedlings, indicating that genetic ploidy may influence the plant's ability to exclude harmful sodium ions. Moreover, the role of symbiotic relationships cannot be ignored, as Yang et al. (2014) demonstrated that arbuscular mycorrhizal fungi can significantly bolster the salt tolerance of seedlings. Understanding whether a variety utilizes "salt-repellent" or "salt-secreting" characteristics is crucial for selecting appropriate rootstocks in mineralized soils (Zhang et al., 2024; Yin et al., 2010).

Rationale for the Present Study in Northern Uzbekistan. Despite the wealth of global research—ranging from the promising forms found in the Crimea region (Arifova et al., 2021) to the high-tech genomic mapping of resistance mechanisms—there remains a critical need for localized, site-specific evaluations. The northern regions of Uzbekistan, specifically the Khanka and Khazarasp districts of the Khorezm region, represent a unique ecological corridor where high soil mineralization, intense atmospheric heat, and chronic water scarcity intersect.

The present study, conducted between 2017 and 2019, seeks to address this gap by evaluating the susceptibility of 21 local and introduced apple varieties on a rigorous 5-point scale. By comparing the physiological performance of autochthonous germplasm, which has adapted over centuries to the local microclimate, against internationally recognized introduced varieties, we aim to identify the most resilient genetic resources capable of thriving in the precarious agricultural landscape of the lower Amu Darya basin.

Methods. The scientific inquiry was conducted between 2017 and 2019 across experimental plots and specialized farming enterprises located in the Khanka and Khazarasp districts of the Khorezm region. These specific geographical zones were selected for their representative environmental challenges, characterized by extreme solar radiation, chronic water scarcity, and progressively increasing soil mineralization—factors that collectively define the agricultural limitations of the lower Amu Darya basin.

Objects of the Study. The research utilized a diverse collection of twenty-one apple varieties, which were categorized into two primary genetic groups to facilitate a comparative analysis:



Local (Autochthonous) Varieties: These include traditional cultivars such as Besh barmog, Sarapayan, and Shur olma, representing germplasm that has evolved through centuries of regional selection.

Introduced (Exotic) Varieties: This group consists of internationally recognized commercial cultivars, including Golden Delicious, Reinette Simirenko, and Starcrimson, sourced from diverse climatic origins to test their plasticity in arid zones.

Assessment of Abiotic Stress Susceptibility. The susceptibility of the plants to detrimental environmental factors was determined through a combination of field observations and laboratory-assisted monitoring, strictly adhering to the standardized protocols established by the Vavilov Institute of Plant Industry (VIR) and regional horticultural research institutes.

A 5-point scoring system was employed to quantify the level of susceptibility, where:

1 Point: Indicated high resistance (minimal susceptibility).

5 Points: Indicated critical damage or plant mortality (maximum susceptibility).

Factor-Specific Evaluation Protocols:

Drought Resistance: This was assessed during periods of acute irrigation deficits by monitoring the leaf apparatus for signs of turgor loss, observing premature fruit abscission, and evaluating the plants' innate ability to maintain metabolic stability despite declining soil moisture levels.

Heat Tolerance: Observations were intensified during the peak summer months (July–August) when ambient temperatures frequently surpassed 40–45°C. Researchers documented the presence of thermal necrosis (sunburn) on both foliage and fruit, while simultaneously assessing the efficiency of the cultivars' transpirational cooling mechanisms.

Salt Tolerance: Conducted in soils naturally affected by chloride-sulfate salinity, this evaluation focused on identifying symptoms of ion toxicity, such as marginal leaf chlorosis and stunted shoot elongation, correlating these visual markers with the laboratory analysis of soil extracts from the root zones.

Data Collection and Statistical Synthesis. Data points were recorded annually, allowing for the accumulation of a robust dataset that reflects the plants' reactions to the fluctuating climatic variables of each successive growing season.

To ensure the scientific integrity of the results, the following metrics were calculated:

Mean Susceptibility (Mean): Representing the characteristic response of a variety to a specific stressor over the entire three-year observation cycle.

Variation Range (Min.-Max.): Capturing the degree of phenotypic plasticity, this range illustrates how much a variety's vulnerability fluctuated in response to the specific meteorological peaks of individual years.

Results and Discussion. The comprehensive data presented in Table 1 offers a profound insight into the physiological resilience and environmental adaptability of various apple cultivars situated within the demanding ecological corridors of the Khorezm region. By examining the susceptibility of twenty-one distinct varieties to drought, heat, and salinity, we can discern critical patterns that differentiate indigenous genetic resources from introduced germplasm, thereby providing a robust foundation for future agricultural optimization in arid zones.

General Comparative Assessment of Local and Introduced Cultivars. Analyzing the results collectively, a distinct trend emerges regarding the adaptive superiority of local varieties when juxtaposed with their introduced counterparts. The indigenous cultivars, having undergone



centuries of natural and artificial selection within the specific microclimates of Khanka and Khazarasp, exhibit significantly lower mean susceptibility scores across all three abiotic stressors.

Indicators of susceptibility to abiotic environmental factors of local and introduced apple varieties in the northern regions of Uzbekistan (Khanka and Khazarasp districts of the Khorezm region, 2017-2019), on a 5-point scale

No.	Variety name	Local/ Introduced	Drought resistance		Heat tolerance		Salt tolerance	
			Mean	Min.-Max.	Mean	Min.-Max.	Mean	Min.-Max.
1.	Besh barmog	Local	1.78	1.33-2.17	1.61	1.33-1.83	2.02	1.33-2.38
2.	Besh yulduz	Local	1.4	1.11-1.67	1.43	1.17-1.71	2.46	2.08-2.83
3.	Eshak olma	Local	1.73	1.04-2.11	1.74	1.05-2.11	1.79	1.16-2.15
4.	Golden Delicious	Introduced	1.49	1.22-1.75	2.12	1.75-2.50	1.52	1.42-1.62
5.	Golden Grimes	Introduced	1.23	0.94-1.38	1.23	0.94-1.38	1.67	1.25-1.87
6.	Jonatan	Introduced	1.68	1.50-2.03	1.71	1.50-2.13	1.66	1.44-2.07
7.	Krasniy Jeleznyak	Introduced	1.8	1.17-2.15	2.07	1.03-3.17	1.44	1.04-2.16
8.	Mayskiy	Local	1.28	0.52-2.17	1.08	1.05-1.12	1.56	0.48-2.11
9.	Muz olma	Local	0.97	0.33-1.33	1.17	0.83-1.33	1.14	0.83-1.33
10.	Nafis	Local	2.09	1.11-3.01	2.05	1.11-3.01	2.2	2.09-2.37
11.	Qishki Khazorasp	Local	1.04	0.63-1.25	1.01	0.75-1.19	1.45	1.25-1.58
12.	Qizil olma	Local	0.93	0.71-1.07	1.21	1.14-1.28	1.86	1.14-2.28
13.	Reinette Simirenko	Introduced	2.27	1.55-2.82	2.58	1.82-3.18	3.15	1.91-4.18
14.	Rozmarin beliy	Introduced	1.34	1.02-1.50	1.56	1.08-2.09	2.1	2.03-2.16
15.	Sarapayan	Local	0.92	0.50-1.16	1.03	0.83-1.17	0.95	0.67-1.14
16.	Shoyi olma	Local	1.22	1.06-1.50	1.23	1.06-1.55	1.63	1.19-2.04
17.	Shur olma	Local	0.9	0.30-1.20	1.04	0.66-1.24	1.13	0.96-1.22
18.	Sokh guzali	Local	1.8	1.17-2.13	1.75	1.13-2.09	2.22	1.15-2.76
19.	Starcrimson	Introduced	1.79	1.09-2.23	1.77	1.15-2.11	1.43	1.04-2.07
20.	Yozgi Khazorasp	Local	0.82	0.33-1.09	1.14	1.07-1.18	1.72	1.67-1.83
21.	Yozgi olma	Local	1.53	0.53-2.11	1.78	1.18-2.08	2.04	1.22-2.48

Conversely, introduced varieties such as Reinette Simirenko and Golden Delicious generally display higher susceptibility indices, particularly regarding salt and heat tolerance. The data reveals that Reinette Simirenko stands out as the most vulnerable variety in this study, recording peak susceptibility mean scores for drought (2.27), heat (2.58), and salt (3.15). Such high values indicate that this cultivar struggles to maintain its physiological integrity when confronted with the high mineralization and thermal extremes characteristic of northern Uzbekistan, potentially leading to reduced yields and diminished fruit quality in commercial orchards.

In-depth Evaluation of Specific Abiotic Resilience.

Drought and Heat Resistance. The correlation between drought and heat susceptibility is palpable, as varieties that succumb to water deficits frequently manifest a corresponding inability to regulate thermal stress.

Top Performers: The local variety Yozgi Khazorasp demonstrated the highest drought resistance with a mean score of 0.82, closely followed by Shur olma (0.90) and Sarapayan (0.92). These cultivars possess an innate ability to manage transpiration and maintain turgor pressure during the peak summer months.

Thermal Stability: In terms of heat tolerance, Qishki Khazorasp (1.01) and Sarapayan (1.03) proved to be exceptionally stable. Their low susceptibility scores suggest the presence of efficient heat-shock protein mechanisms or structural leaf adaptations that minimize cellular damage during periods of extreme atmospheric temperature.

Salt Tolerance: The Khorezmian Challenge. Given the high levels of soil salinity in the Khorezm region, salt tolerance remains the most critical metric for long-term orchard viability.

The Excellence of Sarapayan: Sarapayan emerged as the most salt-tolerant variety across the entire cohort, maintaining a remarkably low susceptibility mean of 0.95. This local treasure represents a vital genetic resource for breeding programs aimed at reclaiming saline lands.

Variable Resilience: Interestingly, while Besh barmoq and Besh yulduz are local varieties, they showed higher-than-average salt susceptibility (2.02 and 2.46, respectively), suggesting that "local" status does not unilaterally guarantee high performance against all stressors.

Introduced Resilience: Among the introduced varieties, Krasniy Jeleznyak and Starcrimson showed relatively competitive salt tolerance scores (1.44 and 1.43, respectively), indicating that certain foreign genotypes may possess latent salt-exclusion or inclusion mechanisms that allow them to persist better than their peers in mineralized soils.

Discussion of Variation and Environmental Interaction. The "Min.-Max." ranges provided in the table illustrate the significant impact of inter-annual climate variability between 2017 and 2019. For instance, Nafis showed a wide drought susceptibility range of 1.11 to 3.01, highlighting a high sensitivity to specific peak-stress events. This volatility suggests that while the variety might perform adequately under moderate conditions, its biological buffers are insufficient to withstand the most extreme peaks of the Uzbek summer.

Note on Introduced Varieties: It is noteworthy that Golden Grimes defied the general trend for introduced cultivars, showing a consistent and relatively low susceptibility across all factors (1.23 for drought/heat and 1.67 for salt). This suggests that Golden Grimes may serve as a suitable candidate for diversification in local orchards, offering a middle ground between the extreme resilience of local types and the high productivity typically associated with introduced varieties.

Conclusion and Recommendations. Concluding this extensive investigation into the ecological plasticity of *Malus domestica* within the Khorezm region, it is paramount to acknowledge the stark divergence in adaptive strategies between the autochthonous populations and those of foreign origin. The empirical evidence gathered over the three-year study period unequivocally demonstrates that local apple varieties represent a vital biological heritage, possessing a profound physiological synergy with the trans-Oxus environment. Having evaluated the susceptibility indices across multiple parameters, it becomes evident that varieties such as Sarapayan, Shur olma, and the Khazorasp series (both Yozgi and Qishki) function as the primary bio-anchors for sustainable viticulture in the northern territories of Uzbekistan.

The vulnerability of introduced cultivars, most notably Reinette Simirenko, highlights the inherent risks of prioritizing international market standards over regional ecological compatibility. While these varieties may offer high yields in temperate climates, their elevated susceptibility to salt and thermal stress—manifesting in mean indices exceeding 2.5 and 3.0 respectively—suggests that their cultivation in Khorezm requires intensive anthropogenic support. Conversely, the resilience of local germplasm, which consistently maintained susceptibility scores near or below the 1.0 threshold, proves that indigenous selection has



successfully "encoded" a high level of drought and salt exclusion mechanisms within these plants.

Strategic Recommendations for Agricultural Optimization. Based on the synthesis of the physiological data and the observed environmental trends, the following recommendations are proposed to enhance the productivity and stability of apple orchards in the Khanka and Khazarasp districts:

Prioritization of Indigenous Germplasm for Land Reclamation: For agricultural zones characterized by high soil mineralization (salinity), it is strongly advised to prioritize the planting of Sarapayan and Shur olma. These varieties, having demonstrated the lowest susceptibility to salt stress (0.95 and 1.13), are ideally suited for "buffer zones" where more sensitive crops would likely fail, thereby ensuring the economic viability of marginal lands.

Selective Integration of Introduced Varieties: If the cultivation of introduced varieties is necessary for export-driven goals, Golden Grimes should be favored over Reinette Simirenko or Golden Delicious. Maintaining a relatively stable performance across all three stress factors, Golden Grimes offers a pragmatic middle ground, providing acceptable resilience without the extreme vulnerability seen in other foreign genotypes.

Implementation of Targeted Mitigation Techniques: For existing orchards housing highly susceptible varieties like Reinette Simirenko or Besh yulduz, it is imperative to implement advanced abiotic stress management. This includes:

Automated Drip Irrigation: To prevent the salt accumulation in the root zone that occurs with traditional furrow irrigation.

Mulching and Shading: Utilizing organic mulches to reduce evaporative water loss and applying light-reflecting sprays (such as kaolin) to mitigate the extreme heat susceptibility noted in the 2017–2019 data.

Genomic Preservation and Breeding Programs: The local variety Sarapayan should be formally recognized as a primary donor for salt-tolerance traits in regional breeding programs. By cross-breeding the high-yield characteristics of introduced varieties with the "environmental immunity" of Sarapayan, researchers can develop a new generation of "hybrid-adaptive" apples capable of thriving in the increasingly arid conditions of Central Asia.

Seasonal Management Adjustments: Recognizing the high variability in drought susceptibility seen in varieties like Nafis, orchardists should adopt a "predictive maintenance" approach. Monitoring local weather forecasts and applying anti-transpirants during identified peak heat windows can prevent the susceptibility indices from reaching the maximum values (e.g., 3.0+) recorded during the study.

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