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PHENOLOGICAL PHASE TRANSITIONS OF APPLE VARIETIES AND THEIR CORRELATION RELATIONSHIPS

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Annotatsiya. *Ushbu maqolada olma navlarida vegetatsiya davrining boshlanishi, gullash fazasi va vegetatsiya davri davomida olma navlari uchun kerak bo'ladigan foydali harorat yig'indisi hamda navlarning fenologik fazalari orasidagi o'zaro bog'liqlik darajasi haqida ma'lumotlar berilgan.*

Kalit so'zlar: *Malus x domestica, fenologik fazalar, gullash, foydali harorat yig'indisi, korrelyatsion bog'liqlik.*

Аннотация. *В данной статье представлены сведения о начале вегетационного периода у сортов яблони, фазе цветения, сумме эффективных температур, необходимых для сортов яблони в течение вегетационного периода, а также об уровне взаимосвязи между фенологическими фазами сортов.*

Ключевые слова: *Malus x domestica, фенологические фазы, цветение, сумма эффективных температур, корреляционная зависимость.*

Abstract. *This article provides information on the onset of the growing season in apple cultivars, the flowering phase, the accumulated effective temperature required for apple cultivars during the growing period, and the degree of correlation between the phenological phases of the cultivars.*

Keywords: *Malus x domestica, phenological phases, flowering, accumulated effective temperature, correlation.*

Introduction. During the growing season, fruit trees undergo specific phenological phases, the onset and timing of which are mainly determined by the genetic characteristics of the cultivars and the environmental conditions in which they grow. The seasonal development of fruit crops is fundamentally based on the hereditary rhythm and regularity of physiological stages [1]. This allows for the selection of early- and late-ripening cultivars and biotypes based on their entry into vegetative and generative growth phases, as well as their early or late flowering tendencies. Recording the developmental characteristics of plants and the duration of specific phenological stages is important for assessing cold resistance and identifying species that are highly adapted to environmental conditions [2]. The onset and completion stages of vegetative development are relatively stable traits of fruit plants that are resistant to cold; however, the later stages of vegetative development tend to show weaker resistance to low temperatures. Among the main abiotic factors that determine physiological processes in plants, the thermal regime plays a key role. The growth processes of fruit trees—specifically, the initiation dates of distinct phenological phases—are closely dependent on changes in heat accumulation [3]. It has been established that the timing of phenological phase transitions in apple cultivars varies depending on the biological characteristics of each cultivar, weather conditions, agricultural practices [1–4], accumulated effective temperatures [5, 6, 7], and the geographical location of the orchard [8, 9].

Materials and Methods. The study was conducted on 14 apple cultivars grafted onto M-IX rootstock, representing various ecological groups. The research was based on the methodology and program developed by the All-Russian Research Institute of Fruit Crop Breeding titled «Methods and Program for the Study of Fruit, Berry, and Nut Plant Cultivars» [10], as well as «Identification of Intensive-Type Cultivars and Study of Seed Fruit Orchard Collections» [11]. Phenological observations and biometric measurements were carried out throughout the growing season in accordance with these methods. All data obtained during the study, including statistical analyses such as correlation analysis, were processed using the Statgraphics Centurion 18 software.

Results and Discussion. As a result of phenological observations, the dates of entry into the main developmental stages of apple cultivars grown in the Tashkent region in 2025 were studied. The cultivar «Farangiz» was chosen as the standard for the study. This cultivar, developed in Uzbekistan, is considered one of the more stable varieties adapted to local climatic conditions. The timing of phenophase transitions in other cultivars was assessed in comparison with the Farangiz cultivar. It was observed that the onset dates of phenological phases varied significantly among different cultivars. Notably, the cultivar Renda entered all phases earlier than the others. Its flowering began as early as March 25, which is 15 days earlier than Farangiz, indicating that its vegetative growth starts very early. This makes it potentially vulnerable to early spring frosts. In contrast, the Sanprays and Israel cultivars were found to enter all phases later than the others, characterized by a relatively delayed onset of vegetative development. For instance, bud swelling in the Israel cultivar began around April 3, which is 4–5 days later than in Farangiz. This delay can be advantageous, allowing the cultivar to avoid damage from early spring frosts.Another noteworthy point is that cultivars introduced from Ukraine and the USA (such as Remo, Liberty Zimniy, and Red Delicious) exhibited certain variability in their entry into phenological development stages. These variations are likely related to the agro-climatic conditions of their regions of origin (Table 1). The period from bud swelling to the end of flowering lasted between 20 to 35 days depending on the cultivar. The duration of this period is determined by the biological characteristics of each cultivar and is directly linked to the accumulated effective temperatures. Overall, the initiation of phenological phases is determined by the genetic traits of each cultivar as well as their level of ecological adaptability.

These indicators are important for breeding work, especially the timing of the onset of the vegetation period and the flowering phase, as they determine the agroecological adaptability of the cultivar. The study presents the dates of the beginning of vegetation and flowering phases of the apple cultivars observed during phenological monitoring, as well as their requirements for accumulated effective temperatures (Table 2).

The earliest onset of vegetation was observed in the Renda cultivar, which required an accumulated temperature sum of 217.0°C (above 0°C) for bud swelling. This value is significantly lower compared to other cultivars, indicating Renda's sensitivity to early spring conditions and its early entry into the vegetation period. In contrast, the Sanprays, Bolajon, and Remo cultivars required more than 350°C of accumulated temperature for vegetation to begin, indicating their later developmental phases. Regarding the flowering phase, there were significant differences among cultivars. The lowest accumulated temperature for the start of flowering was again recorded in Renda (474.5°C above 0°C and 211.3°C above 5°C), confirming that it is an early-flowering cultivar. Conversely, Sanprays, Bolajon, and Starking

Table 1.

Phenological phase transition periods of apple cultivars (2025)

Cultivars	Origin	Bud swelling (day/month)	Bud break (day/month)	Flower bud swelling (day/month)	Start of flowering	Full bloom	End of flowering
Farangiz (control)	Uzbekistan	08/03	19/03	29/03	10/04	13/04	17/04
Prikubanskoe	Ukraine	10/03	18/03	30/03	04/04	09/04	13/04
Renora Zimniy	Ukraine	12/03	19/03	02/04	07/04	10/04	14/04
Remo	Ukraine	09/03	17/03	28/03	30/03	03/04	09/04
Sanprays	Ukraine	09/03	22/03	09/04	12/04	18/04	21/04
Liberti Zimniy	Ukraine	10/03	20/03	30/03	04/04	09/04	12/04
Vagnera Prizovoe	**USA**	07/03	16/03	28/03	07/04	10/04	13/04
Starking Delicious	**USA**	06/03	20/03	02/04	09/04	16/04	19/04
Red Delicious	**USA**	06/03	17/03	27/03	04/04	10/04	14/04
Limonniy	Ukraine	12/03	19/03	30/03	06/04	11/04	15/04
Bolajon	Uzbekistan	09/03	19/03	03/04	11/04	14/04	17/04
Isroil	Uzbekistan	12/03	20/03	03/04	10/04	15/04	19/04
Renda	Ukraine	04/03	11/03	20/03	25/03	29/03	04/04
Qandil Sinap	Crimea	10/03	17/03	24/03	09/04	13/04	17/04

Table 2.

Accumulated effective temperatures during phenological phase transitions of apple varieties (2025)

Names of cultivars	Transition of the vegetation phase		Transition of the flowering phase		
	Day	Average accumulated effective temperature	Day	Temperature sum	
				Above 0°c	Above 5°c
Farangiz (standard)	08/03	301,3	10/04	704,0	361,0
Prikubanskoe	10/03	325,3	04/04	535,8	246,8
Renora Zimniy	12/03	340,5	07/04	605,3	293,3
Remo	09/03	351,5	30/03	528,5	288,8
Sanprays	09/03	353,0	12/04	729,8	424,3
Liberti Zimniy	10/03	335,8	04/04	540,5	251,5
Vagnera Prizovoe	07/03	338,8	07/04	619,8	307,8
Starking Delicious	06/03	287,8	09/04	650,3	371,8
Red Delicious	06/03	314,8	04/04	544,5	255,3
Limonniy	12/03	338,5	06/04	522,0	243,3
Bolajon	09/03	357,2	11/04	651,7	383,7
Isroil	12/03	342,5	10/04	633,0	314,7
Renda	04/03	217,0	25/03	474,5	211,3
Qandil Sinap	10/03	328,3	09/04	623,3	343,8

Delishes cultivars required between 650 and 730°C (above 0°C) to initiate flowering. The delayed entry into the flowering phase indicates that these cultivars prefer warmer conditions and are late-flowering. The standard cultivar Farangiz began vegetation on March 8, with an accumulated effective temperature of 301.3°C. Flowering occurred around April 10, with accumulated temperatures of 704.0°C (above 0°C) and 361.0°C (above 5°C), respectively. These figures show that Farangiz has an average development rhythm and serves as a convenient reference for comparison.

Strong and statistically significant correlations were found between the phenological development stages of the studied apple cultivars (Table 3). Notably, there was a high positive correlation between bud break and both the beginning and end of flowering, with correlation coefficients of r = 0.82 and r = 0.83, respectively. This indicates that the activity level of bud development directly affects the intensity of the flowering process. Additionally, a very strong and statistically significant correlation (r = 0.87; p ≤ 0.001) was observed between flower bud swelling and the start of flowering.

This indicates that there is a consistent sequential relationship among the phenological phases of the cultivars during the vegetation period. Additionally, the correlation between bud swelling and the beginning of flowering was found to be r = 0.38,

Table 3.

Correlation coefficients between phenological phases of apple cultivars (2025)

	1	2	3	4	5
1		0,66	0,49	0,38**	0,46
2	0,66***		0,80	0,82	0,83
3	0,49	0,80		0,87***	0,80
4	0,38**	0,82	0,87		0,94***
5	0,46	0,83	0,80	0,94	

Note: Significant differences at P ≤ 0.05*, P ≤ 0.01** and P ≤ 0.001***. Bud swelling - 1, Bud break - 2, Flower bud swelling - 3, Beginning of flowering - 4, End of flowering - 5.

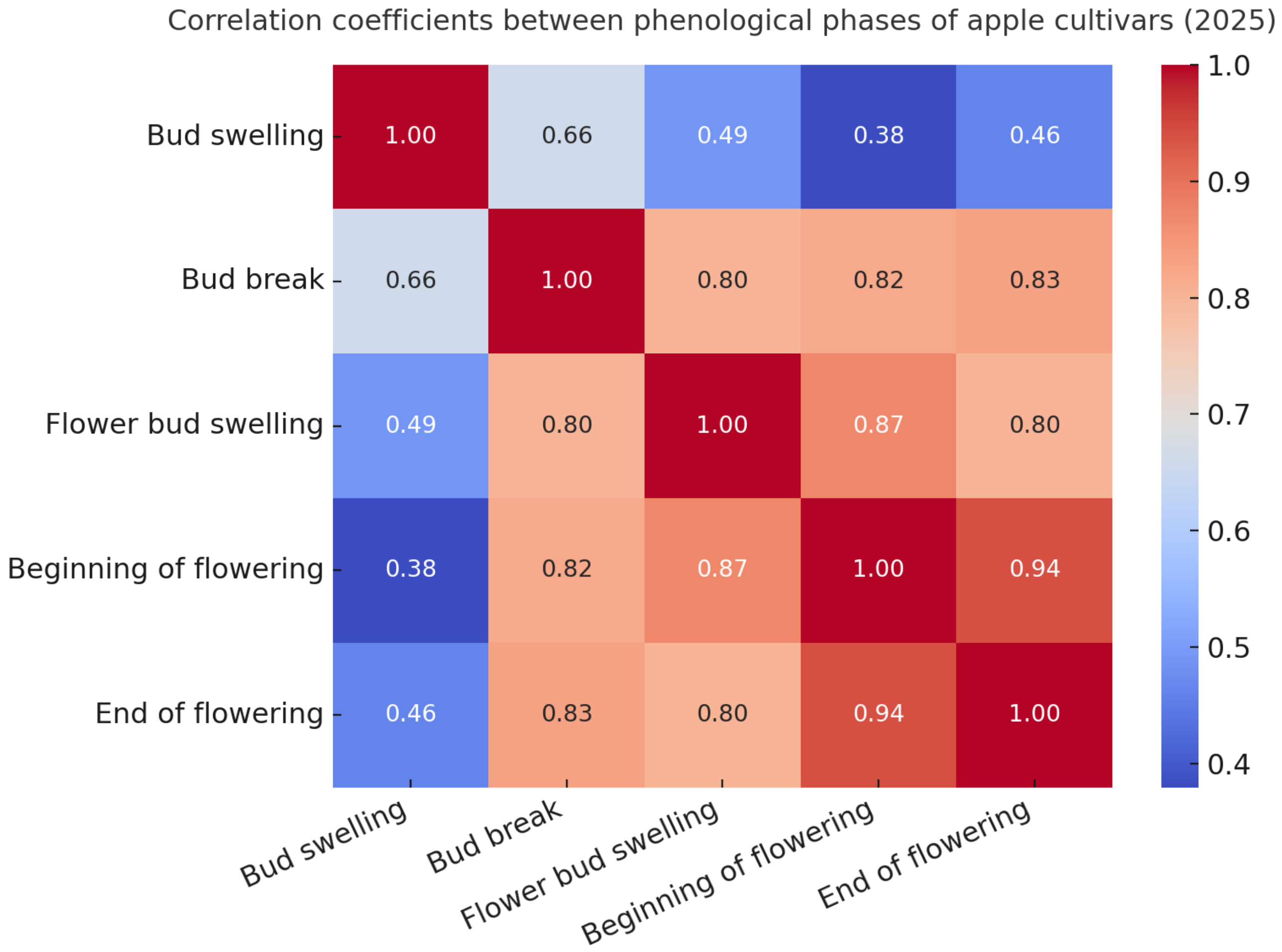

Figure 1. Correlation coefficients between phenological phases of apple cultivars (2025).

which is statistically significant at the $p \leq 0.01$ level. These results are important for forecasting the phenological phases of each cultivar in relation to climatic conditions. Overall, the correlation analysis confirms that the phenological development stages of apple cultivars are highly interrelated and that the sequence and duration of these phases are closely linked to the biological characteristics of each cultivar.

Conclusion and Recommendations. Based on the conducted research, observations indicate that the phenological phases of the cultivars are mainly determined by their origin, ecological adaptability, and genotypic characteristics. As a result of the analysis, the Renda cultivar stood out as the earliest cultivar to enter all phases. This cultivar enters vegetation early and blooms early, indicating its high sensitivity to spring cold weather conditions. In contrast, the cultivars Sanprays, Bolajon, and Isroil entered the vegetation and flowering phases later, which can be considered an advantage providing them with relative resistance to cold.The analysis of accumulated effective temperatures showed that each cultivar requires a specific amount of heat resources to initiate vegetation and reach the flowering stage. Particularly, the required heat accumulation for the beginning of flowering significantly varied among cultivars: in Renda, it was 474.5°C, while in Sanprays and Bolajon, it exceeded 650°C.

Correlation analysis revealed a strong and statistically significant relationship between phenological phases (e.g., between the onset and end of flowering, $r = 0.94$; $p \leq 0.001$). This demonstrates the existence of an intrinsic rhythm and physiological stability in the phenological phases of the cultivars. Especially, a strong positive correlation ($r = 0.87$) was observed between bud swelling and the beginning of flowering, confirming the physiological continuity between these processes.

These scientific findings have great practical importance for breeding and regionalization (zoning) of cultivars, enabling the selection of cultivars that are resistant to spring frosts and develop on time under specific heat accumulations in the context of climate change. Furthermore, based on the required heat accumulation, it is possible to predict the vegetation stages of each cultivar, which lays the foundation for timely planning of agrotechnical measures.

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