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Agrometeorological Characteristics and Phenological Forecasts of Citrus under Modern Climate Conditions

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Abstract. The ecological features of citrus (tangerine, orange, lemon) and the agro-meteorological conditions of their production regions (Adjara, Guria, Samegrelo) are reviewed. The main agro-meteorological characteristics of the citrus distribution regions are given (sums of active temperatures, atmospheric precipitation, relative humidity, number of frost-free days, hydrothermal coefficient). Forecast equations for determining the phenological phases of ripening and flowering of citrus crops are compiled.

The analysis of the climate change scenario shows, that the dynamics of climate change will affect the change in such important agro-meteorological parameters as the duration of the vegetation period, the sum of active temperatures ($>10^{\circ}\text{C}$), etc. Taking into account the above, it was revealed that the predicted changes will have a positive impact on the production of citrus. Against the background of an extended growing season, their distribution area will expand according to vertical zonation. According to the developed scenario, an increase in the duration of the growing season with an increase in air temperature by 1°C is favorable for the full formation of citrus fruits in areas where they are less provided with the sum of temperatures. According to the mentioned scenario, with an increase in temperature by 1°C , the sum of active temperatures (above 10°C) will increase by $240\text{-}260^{\circ}\text{C}$ and as a result, the distribution zones of citrus will first rise by $100\text{-}150\text{m}$ higher than their base (current) distribution zones.

Keywords: Citrus, active temperature, atmospheric precipitation, phenological forecast

Introduction. Typical representatives of the humid subtropical climate (Black Sea coast - Adjara, Guria, Samegrelo) are citrus crops such as lemon, orange, tangerine. Their growth and development depend on agro-meteorological conditions, which determine the possibility of their cultivation, yield and fruit quality. They require a special amount of heat, vegetation begins at a temperature of $10\text{-}11^{\circ}\text{C}$, flowering is observed at a temperature of $16\text{-}18^{\circ}\text{C}$ and lasts $15\text{-}20$ days. The root system of plants begins to develop at a temperature of $11\text{-}12^{\circ}\text{C}$. Fruits begin to grow after the end of flowering and continue to grow intensively for up to 2 months, then this process gradually slows down and stops when the ripening period arrives. Fruit growth depends on the average air temperature and optimal soil moisture. A temperature of $22\text{-}23^{\circ}\text{C}$ is favorable for the growth of these citrus crops.

During the vegetation period, between phenological phases, from bud opening to flowering, the sum of active temperatures above 10°C is required for lemon ("Akhalkartuli"), orange ("Washington Navel") and tangerine ("Unshiu") $400\text{-}560^{\circ}\text{C}$; from flowering to maturity - the sum of active temperatures is $3500\text{-}3700^{\circ}\text{C}$. The amount of atmospheric precipitation from the flowering phase to the maturity phase is $1100\text{-}1750$ mm. In dry zones, additional melioration measures are necessary. Excessive humidity increases the risk of fungal diseases. Relative humidity of $70\text{-}80\%$ is optimal, especially during the flowering period. These crops are characterized by weak frost resistance. Fruits are damaged at temperatures of $-1, -2^{\circ}\text{C}$. Lemon crops die from frost at temperatures of $-8, -9^{\circ}\text{C}$, oranges at $-10, -11^{\circ}\text{C}$, and tangerines at $-11, -12^{\circ}\text{C}$.

Citrus crops develop normally and give high yields on light, nutrient-rich, well-drained, humus-rich soils ($\text{pH}=5.5\text{-}7.5$). In the Black Sea coastal zone of Western Georgia, these crops are grown on peat, humus-carbonate, red soil soils. Wet, strongly alkaline and sandy soils are unfavorable for these citrus crops. Southern, southwestern and southeastern slopes are favorable. It should be noted that the plants should be protected from strong winds by arranging windbreaks [1].

Research object and methodology. The objects of the study were the regions of citrus cultivation - Adjara, Guria and Samegrelo. The Adjara region is located in the humid subtropical zone of Western Georgia, the upper limit of which extends from sea level to an altitude of $500\text{-}600$ m. Above this altitude, it has relatively moderate and continental climatic conditions. The region is bordered by Turkey to the south, the Samtskhe-Javakheti region to the east, the Guria region to the north, and the Black Sea to the west.

The Guria region is characterized by partly hilly, high-mountainous and somewhat sloping, fairly extensive relief conditions directed towards the Black Sea, from sea level to an altitude of 100 m. Hilly and hilly areas are located from sea level to an altitude of approximately 400 m. The region is bordered by the Adjara region to the south, the Samtskhe-Javakheti region to the southeast, the Imereti region to the northeast, the Samegrelo-Zemo Svaneti region to the north, and the Black Sea to the west.

The Samegrelo region is characterized by a flat, hilly terrain. The lowland part of the region (up to $100\text{-}150$ m above sea level) extends quite widely towards the Black Sea. The region is bordered by the Caucasus Mountains to the north, the Imereti region to the east, the Guria region to the south, the Abkhazia region and the Black Sea to the west. As a result of the influence of the Black Sea in the region, the flat, lowland and hilly areas of Samegrelo (up to $500\text{-}600$ m above sea level) are in humid subtropical climate conditions.

For the study regions, multi-year meteorological observation data have been processed and analyzed using the method of mathematical statistics. The meteorological and agro-meteorological databases of the Institute of Hydrometeorology of the Georgian Technical University have been used; the multi-year baseline (current) meteorological observation data of the National Environmental Agency of Georgia for the vegetation period. A scenario (2020-2050) has been developed for Western Georgia, with an increase in air temperature of 1°C. For this, the baseline (current) and forecast future scenario data (2020-2050) of multi-year observations conducted at the meteorological stations of the National Environmental Agency have been used and processed. The climatic parameter of the latter (average air temperature) has been calculated using the ECHAM4 model and according to the A2 scenario.

Results and Discussion. Agroclimatic zone, located from sea level to 500 m altitude, the sum of active temperatures is 4400-3600°C. Citrus fruits develop well in this zone, however, in some years the fruits of citrus crops do not reach full maturity (oranges), especially in the Adjara and Guria regions. The full maturity of mandarin fruits (early varieties) is ensured every year from sea level to 200 m altitude, late mandarin 8-9 times every ten years or more. In the Samegrelo region it is provided every year. At this altitude, the maturity of orange fruits (early varieties) is provided 1-2 times in Adjara and Guria, and 3-4 times in the Samegrelo region. According to the scenario, with a temperature increase of 1°C up to 300 m altitude, full maturity of tangerine (early, late) is expected every year in all regions, only at an altitude of 300 m in Adjara-Guria, full maturity of late tangerine is expected 8-9 times every ten years. Orange (early) at the same altitude 3-4 times (Adjara, Guria), 4-5 times (Samegrelo, Abkhazia) every ten years. Full maturity of tangerine up to 400 m altitude is expected in all regions 8-9 times (early), 6-7 times (late) every ten years. As for the maturity of lemon fruit, it is desirable to harvest it at the time of technical ripeness (light green, slightly yellowish). In this form, lemon fruit indicates a high content of vitamin “C”. Therefore, the sum of temperatures above 10°C, 3800-4000°C, is quite sufficient for it, which ensures the technical ripeness of fruits in the zone every year. In this zone, it is necessary to reliably protect lemon culture from winter frosts. Table 1 shows the main agroclimatic characteristics of citrus-producing regions of Western Georgia [2, 3].

Table 1. Main agroclimatic characteristics of citrus-producing regions in the warm period (IV-X)

Meteo-station	active temperature sum (>10°C)	sum of atmospheric precipitation (mm)	Relative humidity (%)	Frost-free period duration (days)	HTC
Akhalshehi	4300	1470	78	304	3.4
Batumi	4320	1440	80	302	3.3
Keda	3880	800	77	257	2.0
Kobuleti	3990	1360	81	246	3.4
Chakvi	4230	1500	80	282	3.5
Anaseuli	4150	1140	79	277	2.7
Atsana	4020	1130	80	272	2.8
Dablatsikhe	4160	980	74	272	2.3
Supsa	4060	1370	83	267	3.3
Ureki	4380	1180	80	288	2.7
Abasha	4310	790	-	270	1.8
Anaklia	4250	900	83	263	2.1
Zugdidi	4160	1010	79	250	2.4
Martvili	4210	1110	76	257	2.6
Senaki	4520	1000	76	288	2.2
Tsalenjikha	4000	1160	77	255	2.9
Chkhorotsku	4130	1200	-	250	2.9

Sunshine is one of the important factors for the normal course of physiological processes in agricultural crops. If sunshine cannot provide this process, photosynthesis is inhibited, assimilation is weakened, as a result of which the plant has difficulty supplying water and nutrients dissolved in it from the soil. All this affects the productivity of the plant. Therefore, it is necessary to take into account the duration of sunshine in order to create better agroclimatic conditions for plants. The course of the duration of sunshine is satisfactory for the growth and development of citrus fruits and the formation of the crop during the vegetation period of the Adjara region. Frequent sunny days during the flowering and ripening phase of plants are unfavorable. Such days can have a negative impact on the ripening of citrus fruits (late varieties of tangerines and oranges). During the active vegetation period of plants (VI-VIII), average air temperatures in the humid subtropical zone reach 18-23°C, which is favorable for the development of citrus crops. In autumn, according to temperature indicators (20-14°C), conditions for ripening their fruits are better for early tangerines and oranges up to 200-300 m altitude.

In the humid subtropical zone of the Adjara region, in some years, absolute minimum air temperatures of -8, -10°C and above can be observed. Such temperatures are critical, because lemon and orange plants can freeze to the root collar, and tangerines can be severely damaged. Therefore, for 4-5 years, it is possible that we will not be able to get a harvest from

these crops. Therefore, in the fall (November-December), farmers and private sector farmers should use agrotechnical measures to protect against frost (wrapping young citrus plants with three-layer burlap and other materials, piling soil on the trunk of 5-6-year-old plants to a height of 30-35 cm, and other methods). The critical-damaging temperatures for these crops are: -7°C for lemon, -9°C for orange, -11°C for tangerine. The average absolute minimum air temperature in Chakvi, Alambari (Kobuleti region) and Batumi is -4°C , in Khelvachauri, Makhinjauri and Akhalsheeni -5°C , in Chakvi -6°C . In areas where the temperature is -4 , -5 and -6°C , lemon crops (without protection from frost) can freeze once, twice and three times (respectively) every ten years.

Analysis of meteorological observation materials shows that absolute minimum negative air temperatures in the region will be observed in the coastal lowlands of the Black Sea until the end of April, with the exception of Kobuleti. In the citrus growing areas of the Adjara region, negative temperatures are observed everywhere in late autumn (November). However, these temperatures are not particularly critical or damaging for citrus. However, their frost resistance for wintering is weak, since they are not yet fully acclimatized and are also not in a deep state of rest. Therefore, farmers should use agrotechnical measures to protect citrus crops from frost in a timely manner in autumn (October-November).

The territory of the region is from the level of 150-200 m to a height of 10°C , with a temperature sum of 4000°C and above, 50% is provided, the temperature sum of 4000°C and above is satisfactory for the full ripening of lemon, tangerine (early variety) fruits (will ripen fully 9 times every ten years), the late tangerines variety (Unshiu) will ripen 7 times every ten years. Oranges will ripen fully 3 times every ten years, only in Akhalsheeni, Kafandiba, Chakvi and Khelvachauri districts up to an altitude of 100 m [4, 5].

I - Agroclimatic zone covers the coastal lowland of the Black Sea, including the territories of Kobuleti and Khelvachauri, up to an altitude of 100-200 m above sea level. The sum of active temperatures in this zone is more than 4000°C , atmospheric precipitation in the cold period is 1150-1290 mm, in the warm period (IV-X) - 1360-1500 mm. The last frosts in the zone are observed on average on 4.III-15.III, and the first frosts on 2.XII-7.I. The number of days without frost is on average 246-304 days. The zone has favorable conditions for the development of citrus fruits (tangerine, lemon, orange). It should be noted that full ripening of oranges is possible only 5-6 times every ten years.

II - Agroclimatic zone is located at an altitude of 200-400 m above sea level. The sum of temperatures is 3000 - 4000°C , atmospheric precipitation in the cold period - 850-1100 mm, and in the warm period - 800-1330 mm. The duration of the frost-free period (days) is 255-273 days.

The late variety of oranges and tangerines (Unshiu) produced in this zone will not give the desired results due to the lack of the sum of active temperatures. In addition, in these zones (I and II) lemon crops without frost protection measures can freeze 2-3 times, and tangerines once every twenty years. Therefore, in case of severe frosts (-8 , -10°C and above), in order to protect them, the plants should be covered with dry soil (up to 30-35 cm) in the fall. The rooted stem will not freeze, it will survive, and after removing the frozen parts of the plant, we will get young shoots from the stem, which will yield a harvest in 2-3 years. As for young citrus plants, they must be wrapped.

In the Guria region, citrus crops are grown in a humid subtropical zone. In some years, the absolute minimum air temperature in the region can drop to -10 , -12°C and above, which is critical (damaging) for citrus crops. Such temperatures cause their root collars to freeze. As a result, the harvest is expected to be postponed for 4-5 years. Therefore, frost protection measures provided for by agricultural technology should be carried out in November-December. The absolute minimum air temperatures critical to citrus are: -7°C for lemons, -9°C for oranges, -11°C for tangerines.

In the regions of the Guria region, absolute minimum air temperatures are quite often observed until the end of April. For example, in Dablatsikhe -5°C , in Anaseuli -6°C , in Atsana -7°C , in Ureki -4°C , in Lanchkhuti -9°C . Based on the analysis of these absolute minimum temperatures, in some years severe damage to citrus crops is possible. Therefore, agricultural specialists and farmers should choose areas relatively protected from frost when planting new citrus (lemon, tangerine, orange) plantations. In April-May, precipitation in the region is significantly reduced, almost 3-4 times compared to other months. Despite this, it does not pose a particular threat to plants. However, in some years a further decrease in precipitation in this period (IV-V) (50-40 mm and less) is not ruled out. In such a case, a moisture deficit may be noted in the soil, which will negatively affect the flowering of citrus crops. In such unfavorable conditions, it will be necessary to provide the soil with moisture (soil loosening-cultivation, irrigation, etc.).

The territory of the region is mainly provided with 50% of the sum of temperatures of 4000°C and above, depending on the districts, which is sufficient for the full ripening of early varieties of tangerine and lemon fruits. At the mentioned temperature (4000°C), 90% and above, except for Ureki (Ozurgeti) and other districts, the full ripening of citrus fruits cannot be ensured. As for the orange crop, the full ripening of its fruits is expected 2-3 times every ten years, only in Ureki, Anaseuli (Ozurgeti), Lanchkhuti and Dablatsikhe (Chokhatauri). For example, tangerines (Unshiu, a late variety), which require 4200°C and more for full fruit ripening, will reach full maturity in Ureki (Ozurgeti) on November 10, in Lanchkhuti on November 15, in Dablatsikhe and Anaseuli on November 20, in Supsa (Lanchkhuti) on November 25, in Atsana (Ozurgeti) on November 27.

I - Agroclimatic zone is located at an altitude of 10-200 m above sea level. The sum of air temperatures in the zone above 10°C is 4000°C and more. The sum of atmospheric precipitation in the cold period is 800-850 mm, in the warm period - 1000-1370 mm. In this zone, the last frosts are observed on average on 10.III-18.III, and the first frosts on 16.XII-25.XII. The number of days of the frost-free period is 274-290 days. Tangerine and lemon can develop normally in this zone. As for orange, the full maturity of its fruits is ensured 3-4 times every ten years due to the lack of the sum of active temperatures.

II - Agroclimatic zone. Located at an altitude of 200-300 m above sea level. The sum of active temperatures is 3000 - 4000°C . Atmospheric precipitation in the cold period - 850-900 mm, in the warm period - 1000-1200 mm. In the zone, the last frosts are observed on 11.III-21.III, the first frosts on 11.XII-24.XII. The number of frost-free days is 265-288 days.

The given zone has quite favorable agroclimatic resources for the normal development of citrus fruits (tangerine, lemon). It should be noted that in zones I and II, freezing of lemon crops is expected 3-4 times, orange crops 2-3 times every ten years, and tangerine crops once every 15 or more years.

The humid subtropical zone of the Samegrelo region is not immune from severe frosts (-8, -10°C and above) that can severely damage or completely freeze citrus crops and thus cause damage to the economy of the subtropical farming sector. The critical freezing temperature of the root neck of the „Georgian lemon” is -7°C, and of the „Meyer” -9°C. In Poti and Kheta (Khobi), the „Georgian lemon” will freeze to the root neck twice every ten years, and the „Meyer” once.

In the region, the sum of temperatures from sea level to an altitude of 200-300 m completely provide the full maturity of tangerine and lemon fruits, while the full maturity of orange fruits cannot be providing, as they require a sum of active temperatures of 4300°C and higher. Such a temperature can be providing only in the Abasha, Senaki, Khobi districts and partly in the areas adjacent to Poti.

I - Agroclimatic zone covers the territory along the Black Sea coast from sea level to 200 m altitude, where the Abasha, Zugdidi, Martvili, Senaki, partly Tsalenjikha, Khobi and Chkhorotsku districts are located. The sum of active temperatures in the zone is on average 4400°C and slightly higher. The sum of atmospheric precipitation in the cold period is 630-850 mm, in the warm period - 800-1160 mm. The last frosts are observed on average on 15.III-20.III, the first frosts on 2.XII-7.XII. The duration of the frost-free period (days) is on average 252-260 days. In this zone, the above-mentioned factors fully providing the full maturity of citrus fruits from sea level to 200 m above sea level. In this zone, the production of citrus crops, in addition to providing heat, depends on the minimum winter temperatures, where the average characteristics of the absolute minimum air temperature are within the range of -5, -6°C. These temperatures are not critical for citrus, although they are somewhat dangerous for lemons (without protection from frost). In this zone, the area of citrus can be expanded on elevated slopes. In such places, the probability of -8°C frosts, which lead to complete freezing of only lemon is 10-15%, that is Lemons will completely freeze 1-2 times every ten or more years. It is also possible to single out favorable areas for the production of oranges and tangerines without frost protection, where the probability of frosts of -9, -11°C is noted at 10%. Therefore, oranges will completely freeze once every ten years, and tangerines 1-2 times every twenty years.

II - Agroclimatic zone includes the territory adjacent to zone I, as well as the territories of Zugdidi, Chkhorotsku, Tsalenjikha and Martvili districts. It is located at an altitude of 200-500 m above sea level. The sum of active temperatures decreases from 4200°C to 3700°C. The sum of atmospheric precipitation in the warm period is 1160-1220 mm. The last frosts are observed on average on 21.III-29.III, the first frosts on 23.XI-6.XII. The duration of the frost-free period is 236-257 days. In this zone, agroclimatic conditions are favorable only for the development of tangerine and lemon crops (with protection from frost for the latter), where the average absolute minimum temperatures do not exceed -7, -8°C. The distribution area of the mentioned crops in this zone includes foothill areas up to 200-250 m altitude, in some places up to 300 m altitude. At altitudes of the mentioned areas, the probability of frosts of -11, -12°C and above, which can lead to complete freezing of the tangerine crop, will be observed by 10-20%. That is, tangerine will freeze 1-2 times every ten or more years. In some years, when negative temperatures decrease to a critical minimum (-11, -12°C), it will be necessary to use frost protection methods.

Orange - an important export crop. It is used both for fresh fruit and for the production of juice and essential oils. Orange (*Citrus sinensis*) belongs to the family of the Tegan. It is a perennial, heat-loving, evergreen plant. It grows best in subtropical and tropical zones. It is mainly propagated by seedlings obtained by grafting. Seed propagation is rarely used. The optimum temperature is 15-30°C. It prefers light, fertile, well-drained soils. Excessively moist and saline soils are unfavorable, the optimum pH is 5.5-7.5. It requires regular watering, especially during the flowering and fruit formation period. Its main pests are: citrus leaf mite, aphid, and scale. The most common diseases are fungal rot, citrus canker, and phytophthora. The determination of the amount of orange harvest is still in the flowering phase. It is necessary to collect the fruits in a timely manner so that the plant is better prepared for winter and all measures for protection against frost are taken [6, 7, 8].

Four varieties of orange are distinguished by their fruits. In the subtropical conditions of Georgia, the „Hamlin” orange variety is widespread. Its place of origin is Florida (USA). It is characterized by medium-strength growth, early ripening and good ripening [9]. It is distinguished by a pleasant aroma and taste. It ripens in the first half of November and is characterized by regular fruiting and frost resistance. The most frost-resistant of the industrial varieties of orange is “Washington Navel”. It is a low or medium-sized plant with a spreading trunk. The skin of the fruit is smooth, yellow or reddish orange, rich in essential oil. The pulp is juicy and sweet-sour, with a pleasant taste. Its negative side can be considered the cracking of the fruit during frequent autumn rains and the reduction of its durability during storage. As for the red-fleshed orange, it belongs to the group of oranges of European/Italian origin, whose fruit has a red-pink pulp with a specific taste (Figure 1).

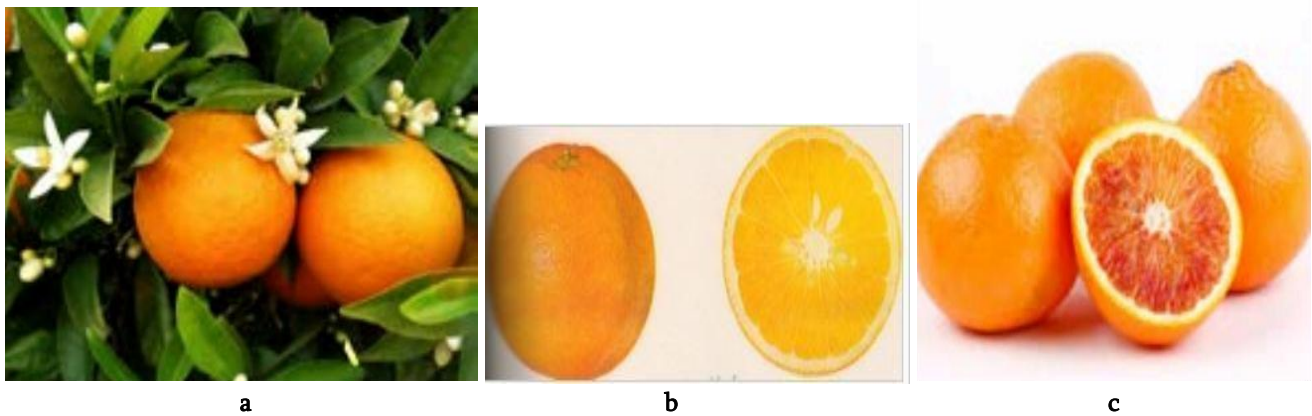


Fig. 1. Orange varieties: a - „Washington Navel”; b - „Hamlin”; c - „Red-fleshed orange”

Tangerine - a citrus evergreen tree or shrub, which is especially important for the subtropical zone. It is characterized by a sweet or sweet-sour taste and is seeded or seedless, depending on the variety. The optimum temperature for tangerine is 12-30°C; it is damaged at temperatures below -6°C (especially during flowering); requires lighting and a place protected from the wind. When choosing a place for growing tangerine, microclimatic conditions should be taken into account - relief, height above sea level. Biological requirements of individual varieties for overwintering conditions. In the case of its production, light or medium mechanical composition soils (pH - 5.5–7.0), with good drainage, are preferable. It does not adapt to excessively wet, saline soils. Among the varieties widespread in Georgia, the famous „Unshiu”, whose homeland is considered to be Japan. Currently, its distribution covers an area of 19 thousand hectares. Its tree is strong-growing, compact, with an oval trunk. The fruit has a sweet-sour taste. It contains 6.17% sugars, acidity is 0.98%, vitamins - 36-38%. This variety is high-yielding, withstands frosts of -10, -12°C. „Kovano-Wase” is an early form of „unshiu”, ripens very early. It is characterized by a sweet-sour taste, high marketable quality and is widely used for export. It enters fruiting in the second-third year after planting, the fruits ripen in the first half of October. Among its early varieties, the following are known: „Miyagawa-Wase”, „Okitsu-Wase”, „Miko-Wase”, „Tiahara-Wase”. The variety „Georgian Early” is a somatic mutant of “Unshiu”. It is characterized by an aromatic, sweet-sour taste compared to “Unshiu” and the fruits ripen 25 days earlier. The dates of picking mandarins vary depending on the region and variety. The early varieties „Kovano Vase” and „Georgian Early” are harvested from the second half of October, the late variety „Unshiu” in November (Figure 2).

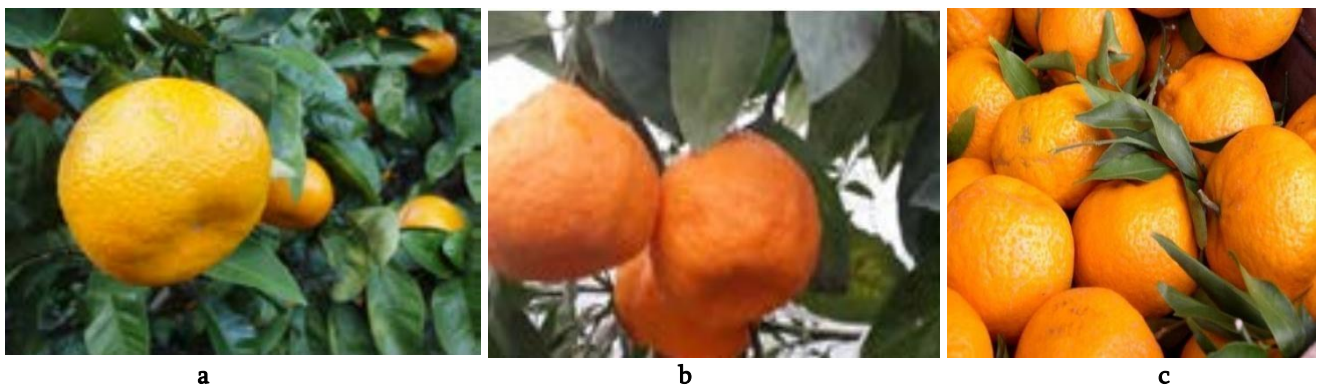


Fig. 2. Tangerine varieties: a - „Unshiu”; b - „Kovano Vase”; c - „Georgian Early”

Lemon - an evergreen tropical plant. Its fruits are oval or oblong, yellow, with a sour taste, are used raw, as citric acid. Due to its specific aroma, essences are prepared from its fruits. It contains: acids 3.5-8.1%, sugars - 1.9-3%, vitamin C - 45-140 mg/100g, as well as vitamins P and B, pectin substances, phosphorus, potassium, calcium and magnesium. Lemon culture is very demanding on temperature conditions. The optimal temperature for its development is 18–25°C, flowers, buds and fruits die at temperatures of -1, -1.5°C, ripe fruits - 1.5, 2.8°C. In the lemon-producing regions of Georgia, its vegetation begins in spring and ends in late autumn. The flowering phase occurs in spring, and before harvesting, an average of 200-220 days are required, with active temperature sums of at least 3500°C. On the Black Sea coast, active temperature sums are within 4100-5000°C, which is sufficient for lemon cultivation. Of all citrus crops, it is most damaged by prolonged droughts. Despite the fact that lemon is light-loving, it adapts well to shading. It successfully develops on light, humus-rich, well-drained soils and is characterized by high water requirements.

The following lemon varieties are mainly distributed in the Guria and Samegrelo regions of Adjara: „Georgian Lemon”, „Villafranca”, „Meyer”, „Dioscuria”. Local (Georgian) forms of lemon are local populations selected over centuries, well adapted to the conditions of Western Georgia, distinguished by their aroma and stable fruiting. „Georgian lemon” is one of the most common varieties in Georgia. It is characterized by high yield, large fruit size and thin skin. „Villafranca”, characterized by high aroma, medium acidity and good fruit yield. Along with other common varieties (e.g. „Lubon”,

„Eureka”), this variety is well adapted to the local subtropical climate. „Meyer” lemon is a hybrid of lemon and orange, less acidic. It is relatively tolerant of low temperatures (Figure 3).

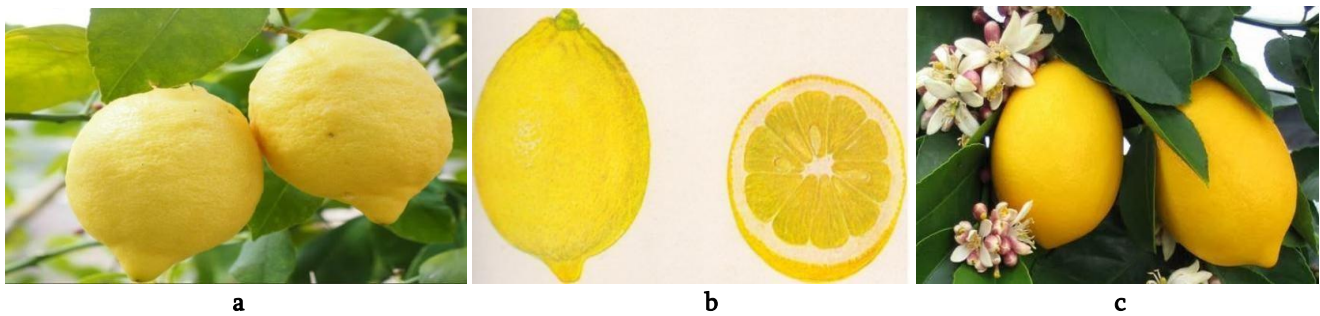


Fig. 3. Lemon varieties: a - „Georgian lemon”; b - „Villafranca”; c - „Meyer”

The forecast of flowering of lemon, orange and tangerine is based on the dependence of flowering dates on the duration of the period from February 1 to the date of bud break; the forecast of fruit maturity - on the dependence of maturity dates on the duration of the period from March 1 for lemon and orange, from April 1 for tangerine. The following regression equations are used to forecast the flowering dates of the above crops:

$$y = -0.72x + 94 \text{ for lemon}$$
$$y = -0.81x + 101 \text{ for orange}$$

In the formulas, y is the expected flowering date (number of days from the date of bud break to the date of flowering); x - the number of days from February 1 to the date of bud break.

The following regression equations have been compiled to predict the maturity dates of tangerines, lemons and oranges:

$$n = -0.68n_1 + 200 \text{ for tangerine („Unshiu”)}$$
$$n = -0.73n_1 + 245 \text{ for lemon („Villafranca”)}$$
$$n = -0.81n_1 + 257 \text{ for orange („Washington Navel”)}$$

In the equations, n is the date of fruit ripening (i.e. the number of days from the date of the beginning of flowering to the date of fruit ripening), n_1 is the number of days from March 1 for lemons and oranges, from April 1 to the date of the beginning of flowering for tangerines. The forecast error is 7-8 days, and the lead time is 4-5 days.

Based on the baseline meteorological data and the scenario-developed temperature increase by 1°C, the dates of a stable transition of the average daily air temperature above (in spring) and below (in autumn) by 10°C were determined, and the sums of active temperatures were calculated between these dates. The given data are related to the height above sea level (m), since the change in the mentioned indicators is directly related to the heights. These indicators were processed by the method of mathematical statistics, where close correlations were revealed. Based on the above connections, regression equations have been compiled (scenario, with a temperature increase of 1°C for Western Georgia):

$$n = 0.027h + 51 \text{ (for determining the date of temperature above } 10^\circ\text{C)}$$
$$T = -16.711n - 1.127h + 5496 \text{ (for determining the sum of active temperatures)}$$

In the equations, n - the date of the air temperature exceeding 10°C is 1 - from February (i.e. the number of days from February 1 to the date of the temperature exceeding 10°C), h - height above sea level (m), T - the sum of active temperatures above 10°C.

According to the equations, when determining the sums of active temperatures, first of all, the date of the air temperature exceeding 10°C must be determined using the appropriate equation (i.e. the number of days from February 1 to the date of the temperature exceeding 10°C). By inserting the obtained number of days into the equation for determining the sum of active temperatures, the appropriate sum of temperatures is obtained.

Conclusion. Analysis of existing climate data and climate change scenarios shows that the dynamics of climate change, over the next few decades, will have a noticeable impact on changes in such important agro-meteorological parameters as the duration of the growing season (will increase), the sum of active temperatures (will increase), etc. Taking into account the above, it was revealed that current and projected climate changes will in some cases have a positive impact on the production of some citrus crops. Against the background of an extended growing season, their distribution area will expand according to vertical zonation. Citrus species, such as orange culture, will reach full maturity. However, it will be necessary to additionally use effective irrigation systems (drip), mulching. Global temperature increase will also contribute to the spread of pests and diseases. The changed precipitation regime, in particular, intensive precipitation, may lead to soil erosion and a reduction or loss of crops. Prolonged droughts are also a threat.

According to the developed scenario, with an increase in air temperature by 1°C, the determination of the dates of the onset of temperatures above 10°C (in spring) and below it (in autumn) showed that in spring it begins on average 6 days earlier, and in autumn it ends below 10°C by the same number of days later, compared to the dates of the onset of the base (existing) multi-year air temperature above 10°C. Therefore, according to the scenario, the duration of the vegetation period increases, which will be favorable for the growth and development of citrus crops and the full formation of the crop. In particular, in areas where crops are less provided with the sum of temperatures.

Due to global climate warming, according to the scenario, with a temperature increase of 1°C, the sum of active temperatures (above 10°C) will increase by 240-260°C and more. As a result, the distribution zones of citrus crops will initially rise by 100-150 m, compared to their base (current) distribution zones.

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Agrometeorological characteristics and phenological forecasts of citrus under modern climate conditions /Maia Meladze, Giorgi Meladze/ Transactions IHM, GTU. -2026. -vol.139. -pp.72-79. - Georg., Summ. Georg., Eng.Rus.

The ecological features of citrus (tangerine, orange, lemon) and the agro-meteorological conditions of their production regions (Adjara, Guria, Samegrelo) are reviewed. The main agro-meteorological characteristics of the citrus distribution regions are given (sums of active temperatures, atmospheric precipitation, relative humidity, number of frost-free days, hydrothermal coefficient). Forecast equations for determining the phenological phases of ripening and flowering of citrus crops are compiled.

The analysis of the climate change scenario shows, that the dynamics of climate change will affect the change in such important agro-meteorological parameters as the duration of the vegetation period, the sum of active temperatures (>10°C), etc. Taking into account the above, it was revealed that the predicted changes will have a positive impact on the production of citrus. Against the background of an extended growing season, their distribution area will expand according to vertical zonation. According to the developed scenario, an increase in the duration of the growing season with an increase in air temperature by 1°C is favorable for the full formation of citrus fruits in areas where they are less provided with the sum of temperatures. According to the mentioned scenario, with an increase in temperature by 1°C, the sum of active temperatures (above 10°C) will increase by 240-260°C and as a result, the distribution zones of citrus will first rise by 100-150m higher than their base (current) distribution zones.

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ციტრუსოვანი კულტურების აგრომეტეოროლოგიური მახასიათებლები და ფენოლოგიური პროგნოზები კლიმატის თანამედროვე პირობებში /მაია მელაძე, გიორგი მელაძე/ სტუპ-ის ჰმ-ის შრომათა კრებული-2026.- ტ.139.-გვ. 72-79. -ქართ., რეზ. ქართ., ინგლ., რუს.

განხილულია ციტრუსების (მანდარინი, ფორთოხალი, ლიმონი) ეკოლოგიური თავისებურებანი და მათი მწარმოებელი რეგიონების (აჭარა, გურია, სამეგრელო) აგრომეტეოროლოგიური პირობები. მოცემულია ციტრუსების გავრცელების რაიონების ძირითადი აგრომეტეოროლოგიური მახასიათებლები (აქტიურ ტემპერატურათა ჯამები, ატმოსფერული ნალექები, შეფარდებითი ტენიანობა, უყინვო დღეთა რიცხვი, ჰიდროთერმული კოეფიციენტი). შედგენილია ციტრუსოვანი კულტურების სიმწიფის და ყვავილობის ფენოლოგიური ფაზების განსაზღვრის საპროგნოზო განტოლებები.

კლიმატის ცვლილების სცენარის ანალიზი აჩვენებს, რომ კლიმატის ცვლილების დინამიკა გავლენას მოახდენს ისეთი მნიშვნელოვანი აგრომეტეოროლოგიური პარამეტრების ცვლილებაზე, როგორცაა, სავეგეტაციო პერიოდის ხანგრძლივობა, აქტიურ ტემპერატურათა ჯამი და ა.შ. აღნიშნულის გათვალისწინებით, გამოიკვეთა, რომ პროგნოზირებული ცვლილებები პოზიტიურ გავლენას მოახდენს ციტრუსოვანი კულტურების წარმოებაზე. გახანგრძლივებული სავეგეტაციო პერიოდის ფონზე გაფართოვდება მათი გავრცელების არეალი ვერტიკალური ზონალობის მიხედვით. შემუშავებული სცენარით, ჰაერის ტემპერატურის 1°C-ით მატებისას სავეგეტაციო პერიოდის ხანგრძლივობის ზრდა ხელსაყრელია ციტრუსოვანი კულტურათა ნაყოფების სრული ფორმირებისათვის იმ ადგილებში, სადაც ისინი ტემპერატურის ჯამით ნაკლებად არიან უზრუნველყოფილი. აღნიშნული სცენარით, ტემპერატურის 1°C-ით მატებისას აქტიურ ტემპერატურათა ჯამი (10°C-ის ზევით) მოიმატებს 240-260°C-ით და შედეგად ციტრუსოვანი კულტურების გავრცელების ზონები პირველად 100-150 მ-ით აიწევს მაღლა, მათი გავრცელების საზღვარი (მიმდინარე) ზონებთან შედარებით.

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Агрометеорологические характеристики и фенологические прогнозы цитрусовых культур в современных климатических условиях /Майя Меладзе, Гиоргий Меладзе/ Сб. Трудов ИГМ ГТУ. - 2026. – том 139. - с. 72-79. - Груз.; Рез: Груз., Англ., Рус.

Рассмотрены экологические особенности цитрусовых культур (мандарин, апельсин, лимон) и агрометеорологические условия регионов их производства (Аджария, Гурия, Самегрело). Приведены основные агрометеорологические характеристики регионов распространения цитрусовых (суммы активных температур, атмосферные осадки, относительная влажность, количество безморозных дней, гидротермический коэффициент). Составлены уравнения прогнозирования для определения фенологических фаз созревания и цветения цитрусовых культур.

Анализ сценария изменения климата показывает, что динамика изменения климата повлияет на изменение таких важных агрометеорологических параметров, как продолжительность вегетационного периода, сумма активных температур и др. С учетом вышеизложенного выявлено, что прогнозируемые изменения окажут положительное влияние на производство цитрусовых культур. На фоне продленного вегетационного периода их ареал распространения расширится по вертикальному зональному признаку. Согласно разработанному сценарию, увеличение продолжительности вегетационного периода при повышении температуры воздуха на 1°C способствует полноценному формированию цитрусовых плодов в районах с недостаточным количеством температур. По указанному сценарию, при повышении температуры на 1°C сумма активных температур (выше 10°C) увеличится на 240-260°C, и в результате зоны распространения цитрусовых культур в первые поднимутся на 100-150 м выше по сравнению с их базовыми (текущими) зонами распространения.