

Studying of the biological characteristics of introduced rare citrus taxa in the humid subtropics of Russia as one of the elements of preserving and increasing plant biodiversity

Alexander Kuleshov^{1*}, and Raisa Kulyan¹

¹Federal Research Center "Subtropical Scientific Center of the Russian Academy of Sciences", 2/28, Jan Fabricius, Sochi, 354002, Russia

Abstract. The study is devoted to the study of the biological characteristics of introduced citrus taxa. The study of the biological characteristics of plants in various soil-climatic zones is of great scientific and practical importance, and is an essential element in preserving and increasing biodiversity by new introduced plant species. As a result of the research, the forms *C. maxima* 'Sambokan', *C. × meyeri*, *C. × limetta* 'Chontipico' and *C. × limonelloides* were isolated, which can be recommended for creating plantings in open ground and cultivation structures with uncontrolled conditions in the humid subtropics of Russia. Taxa *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × limonelloides*, *C. × meyeri*, *C. × myrtifolia*, *C. × latifolia*, *C. × bergamia*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. × meyeri*, *C. medica* var. *sacrodactylus*, distinguished by its decorative qualities, can be recommended as an extension crop in demonstration areas, as well as for the design of winter gardens, terraces and interiors in various rooms.

1 Introduction

One of the main problems of humanity around the world is the conservation of plant biodiversity [1]. Plant biodiversity is one of the main sources of valuable information for new scientific discoveries in the field of agriculture and medicine. In addition, it satisfies the needs of humanity with basic raw materials, and with the development of genetic technologies, it contributes to the acquisition of new genetic information that will be valuable for breeding programs and the creation of more productive plantings of agricultural crops with varieties more resistant to biological and environmental stress [2].

As a result of natural and artificial hybridization, a large species and varietal diversity of the Citrus genus was obtained. Currently, citrus plants are one of the most popular fruit crops for commercial cultivation in countries located in the subtropical and tropical climate zones [3,4]. The collection of citrus fruits of the Federal Research Center "Subtropical Research Center of the Russian Academy of Sciences" includes 144 genotypes obtained as

* Corresponding author: subtrop.alexandr24@gmail.com

a result of the breeding work of the Center and introductions from various countries of the world [5]. Among the introduced citrus plants, there are species and varieties classified as rare.

One of the ways to preserve plant biodiversity, including citrus fruits, is to use ex situ methods, i.e. keeping plants in conditions atypical for their natural habitat [6-8]. These methods contribute to the conservation of endangered, rare, ornamental and medicinal species of agricultural crops [9-10]. The humid subtropics of Russia are the northernmost region for the cultivation of citrus crops. Many collectible citrus taxa are heat demanding and sensitive to negative and low positive temperatures. Therefore, they are grown in protected soil, but in the subtropics of Russia, heat-loving citrus taxa can be grown in cultivation facilities with uncontrolled conditions. The study of the biological characteristics of plants in various soil-climatic zones is of great scientific and practical importance, and is an essential element in preserving and increasing biodiversity by new plant species. Also, the data obtained will be important and useful in production and breeding programs. Therefore, this scientific work was devoted to the study of the biological characteristics of rare citrus taxa of different ecological and geographical origins, the study of which had not previously been carried out in the humid subtropics of Russia.

2 Materials and methods

The studies were conducted in 2020–2022. in the humid subtropics of Russia on the basis of the bioresource collection of citrus fruits of the Federal Research Center SSC RAS in a greenhouse with uncontrolled conditions, located in the village. Razdolnoye, Khostinsky district, Sochi. Geographical coordinates of the place of growth: 43°60' north latitude and 39°76' east longitude. Plants were grafted onto *C. trifoliata* rootstock in 2015. There are 13 variants in the experiment (plant - variant), repetition - three times. Objects of study: *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × latifolia*, *C. × bergamia*, *C. ichangensis*, *C. limon* 'Del Brasil', *C. × limonelloides*, *C. × limetta* 'Chontipico', *C. maxima* 'Sambokan', *C. medica*, *C. medica* var. *sarcodactylus*, *C. × meyeri*, *C. × myrtifolia*. The study of biological characteristics was carried out according to generally accepted methods.

3 Results

As a rule, all citrus crops are perennial evergreens, without obvious winter dormancy, that is, under favorable conditions they grow throughout the year. At the same time, growing shoots, ripe fruits, buds, flowers and ovaries can be found on trees.

The annual development cycle of citrus fruits begins with bud bursting (1st active growth), which in fruit-bearing plants occurs together with the budding phase. As a result of studying 13 taxa of the genus *Citrus* in the period from 2020 to 2022, it was found that bud bursting and budding began when a stable average daily temperature reached above +13 °C, when the sum of active temperatures (SAT) reached 200–345 °C depending on the taxon and weather conditions of the year. In the humid subtropics of Russia, this period begins in the II-III decade of March (Table 1).

It was found that, as a result of long-term observations, there was no significant variation in the onset of the “bud break and budding” phase in the studied citrus taxa. Thus, the studied taxa of citrus fruits were divided into early, middle and late according to the timing of the onset of the “bud break and budding” phase. Taxa with early emergence from winter dormancy include *C. aurantifolia*, *C. × latifolia*, *C. limon* 'Del Brasil', *C. × meyeri* and *C. maxima* 'Sambokan' (2nd decade of March); *C.* has the latest start of the growing season. *ichangensis* (1st decade of April). An intermediate position is occupied by *C.*

aurantifolia ‘Foro’, *C. × bergamia*, *C × limonelloides*, *C. × limetta* ‘Chontipico’, *C. medica*, *C. medica* var. *sacrodactylus* and *C. × myrtifolia* (III decade of March). The difference between taxa with an early onset of the phenological phase “bud break and budding” is 4 days (16.03–20.03), in the middle group 6 days (18.03–25.03), the difference from the early onset of *C. aurantifolia* (03/16) and the late *C. ichangensis* (01.04) is 14–20 days.

Since citrus crops are evergreens, their life cycle is not limited in the activation of growth processes, therefore cyclical growth is observed. During one year of growing season, citrus fruits are able to re-activate growth processes, the number and duration of which depend on genetic characteristics, weather conditions of the season, characteristics of agricultural technology and a number of other factors.

Table 1. Features of growth and development of rare citrus taxa.

Taxon	1st active growth			2nd active growth			3rd active growth		
	Start, date	SAT, °C	Duration, days	Start, date	SAT, °C	Duration, days	Start, date	SAT, °C	Duration, days
<i>C. aurantifolia</i>	16.03	209	56	30.07	2190	36	02.10	3700	43
<i>C. × latifolia</i>	18.03	200	57	19.07	1880	37	15.10	3950	38
<i>C. limon</i> ‘Del Brasil’	20.03	223	52	22.07	1960	18	-	-	-
<i>C. maxima</i> ‘Sambokan’	19.03	223	52	20.07	1820	24	-	-	-
<i>C. × meyeri</i>	19.03	209	56	30.06	1420	27	06.09	2350	30
<i>C. aurantifolia</i> ‘Foro’	23.03	223	56	11.07	1720	47	25.09	3650	41
<i>C. × bergamia</i>	24.03	272	54	05.08	2170	25	11.10	3740	26
<i>C. × limonelloides</i>	23.03	251	50	23.07	1870	35	07.10	3670	33
<i>C. × limetta</i> ‘Chontipico’	21.03	241	56	27.07	1920	37	01.10	3500	34
<i>C. medica</i>	26.03	297	42	01.08	2080	32	-	-	-
<i>C. medica</i> var. <i>sacrodactylus</i>	26.03	272	42	29.07	2020	36	23.10	3990	29
<i>C. ichangensis</i>	01.04	345	32	01.08	2130	18	-	-	-
<i>C. × myrtifolia</i>	28.03	334	45	04.07	1440	32	12.09	3170	24

It has been established that rare citrus taxa exhibit from 2–3 to 5 periods of active growth during the growing season, their number depending on genetic characteristics. As a result of observations in *C. aurantifolia*, *C. aurantifolia* ‘Foro’, *C. × latifolia*, *C. × bergamia*, *C × limonelloides*, *C. limetta* ‘Chontipico’, *C. × meyeri*, *C. medica* var. *sacrodactylus* and *C. × myrtifolia*, three periods of active growth were identified, and under favorable weather conditions (prolonged temperatures above +10 °C), a 4th wave of shoot growth can be observed in the autumn-winter period. *C. ichangensis*, *C. limon* ‘Del Brasil’, *C. maxima* ‘Sambokan’, *C. medica* are characterized by two periods.

Spring growth of shoots is more extended; the shortest duration was observed in *C. ichangensis*, which was 32 days; for other taxa studied, the values range from 42 (*C. medica* and *C. medica* var. *sacrodactylus*) to 57 days (in *C. × latifolia*). When the sum of active temperatures reaches 1420–2190 °C, rare taxa of citrus fruits experience a second active growth, and at 2350–3990 °C a third active growth occurs.

One of the main phenophases in the development of fruit plants is “blooming”. Thanks to this phenological phase, including its duration, it is possible to estimate the future harvest. According to our records and observations, it was found that from the appearance of a bud to the opening of the petals in rare citrus taxa, it takes from 17 (*C. aurantifolia*

'Foro' in 2020) to 46 days (*C. × limetta* 'Chontipico' in 2022). According to the flowering period, taxa with early, middle and late flowering were distinguished (Table 2.).

Table 2. Peculiarities of flowering of rare citrus taxa.

Taxon	Bloom			Duration of flowering, days	Repairability	SAT, °C
	Start	Massive	End			
Early flowering						
<i>C. aurantifolia</i> 'Foro'	11.04	22.04	17.05	36	+	465
<i>C. aurantifolia</i>	12.04	23.04	12.05	32	+	476
<i>C. × meyeri</i>	12.04	21.04	15.05	33	+	476
<i>C. × latifolia</i>	13.04	23.04	15.05	32	+	486
<i>C. limon</i> 'Del Brasil'	13.04	23.04	12.05	29	+	486
Medium flowering						
<i>C. ichangensis</i>	18.04	23.04	03.05	14	-	545
<i>C. × myrtifolia</i>	19.04	27.04	13.05	23	-	532
<i>C. maxima</i> 'Sambokan'	21.04	29.04	11.05	20	-	583
Late flowering						
<i>C. × limonelloides</i>	23.04	03.05	13.05	22	+	604
<i>C. medica</i> var. <i>sacrodactylus</i>	23.04	29.04	08.05	14	-	604
<i>C. × bergamia</i>	25.04	03.05	18.05	23	+	625
<i>C. medica</i>	25.04	30.04	08.05	14	-	625
<i>C. × limetta</i> 'Chontipico'	28.04	04.05	17.05	18	+	660

The taxa *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × latifolia*, *C. limon* 'Del Brasil', *C. × meyeri* are distinguished by their early flowering period. Flowering occurs at the beginning of the second decade of April (on average April 11–13) and lasts for 21–33 days. Average flowering time: *C. ichangensis*, *C. maxima* 'Sambokan' and *C. × myrtifolia*. Flowering occurs at the end of the second ten days of April (on average April 18–19), which lasted 13–20 days. The taxa *C. × bergamia*, *C. × limonelloides*, *C. × limetta* 'Chontipico', *C. medica*, *C. medica* var. *sacrodactylus*. Flowering occurs in the third decade of April (on average April 23–28) with a duration of 11–17 days.

A distinctive feature of citrus taxa from other fruit crops is the manifestation of remontancy during repeated growth processes, since the formation of fruit buds is interconnected with vegetative growth. As a result of research, remontancy was noted in *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × latifolia*, *C. × bergamia*, *C. × limonelloides*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. × meyeri*. In some taxa, such as *C. × bergamia*, *C. limon* 'Del Brasil', *C. × limetta* 'Chontipico', *C. medica* var. *sacrodactylus*, fruit set after repeated flowering may not be observed or the fruits may have low commercial quality in comparison with fruits from spring flowering.

It has been established that the onset of the "blooming" phenophase, according to average long-term studies, in early taxa occurs at the sum of active temperatures of 465–486 °C, in taxa with an average flowering period at 532–583 °C, and in late taxa – 604–660 °C. The difference between citrus taxa with early and late flowering averaged 13 days, which in turn varied depending on the conditions of the year.

All studied taxa are ranked according to the timing of fruit ripening.

- Early ripening taxa – *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × latifolia*, *C. × limonelloides*, *C. × meyeri* (III decade of November – 1st decade of December).
- Mid-ripening taxa – *C. ichangensis*, *C. × bergamia*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. maxima* 'Sambokan' and *C. medica* var. *sacrodactylus* (1st–2nd decade of December).

- Late ripening taxa – *C. medica* and *C. × myrtifolia* (3rd decade of December – 1st decade of January) (Table 3).

Table 3. Peculiarities of ripening and economic characteristics of fruits of rare citrus taxa.

Taxon	Fruit ripening		SAT, °C	Fruit weight, g	Harvest, kg/tree
	Decade/month	In days			
<i>C. aurantifolia</i>	III/11	189	4950	30.3 ±1.6	1.4±0.14
<i>C. aurantifolia</i> ‘Foro’	III/11	182	5070	46.8 ±2.9	1.2±0.18
<i>C. × latifolia</i>	III/11	192	5030	91.7 ±24.0	1.4±0.02
<i>C. ichangensis</i>	I/12	222	5012	46.7 ±11.2	0.6±0.31
<i>C. × bergamia</i>	II/12	215	5140	106.2 ±19.5	2.4±0.53
<i>C. × limonelloides</i>	III/11	191	4880	48.6 ±7.3	2.0±0.05
<i>C. × limetta</i> ‘Chontipico’	I/12	201	4990	111.2 ±54.2	1.6±0.16
<i>C. limon</i> ‘Del Brasil’	I/12	205	4800	169.8 ±84.9	2.2±0.17
<i>C. maxima</i> ‘Sambokan’	II/12	219	5200	231.4 ±94.3	4.2±0.86
<i>C. medica</i>	III/12	225	5250	162.2 ±10.7	0.9±0.11
<i>C. medica</i> var. <i>sarcodactylus</i>	II/12	226	5160	145.7 ±15.9	1.1±0.20
<i>C. × meyeri</i>	III/11	191	4710	115.2 ±16.7	2.6±0.39
<i>C. × myrtifolia</i>	III/12	221	5157	43.6 ±8.1	0.5±0.06
NSR _{0,5}	-	-	-	42.0	0.31

From the beginning of the growing season until fruit ripening, rare citrus taxa require a sum of active temperatures in the range of 4710–5250 °C. For early ripening taxa: 4710–5070 °C, for middle ripening: 4990–5140 °C, for late ripening: 5150–5250 °C.

Small-fruited taxa include *C. aurantifolia*, *C. aurantifolia* ‘Foro’, *C. ichangensis*, *C. × limonelloides*, *C. × myrtifolia* (30.3–48.6 g); to medium-fruited varieties – *C. × latifolia*, *C. × bergamia*, *C. × limetta* ‘Chontipico’ and *C. × meyeri* (91.7–115.2 g); to large-fruited ones – *C. limon* ‘Del Brasil’, *C. maxima* ‘Sambokan’, *C. medica* and *C. medica* var. *sarcodactylus* (45.7–231.4 g).

As a result of long-term observations, it was found that the highest productivity indicators were noted for the taxon *C. maxima* ‘Sambokan’, the average yield was 4.2 kg/tree, followed by such taxa as *C. × bergamia* (2.4 kg/tree), *C. limon* ‘Del Brasil’ (2.2 kg/tree) and *C. × meyeri* (2.1 kg/tree). The lowest rates were observed in the taxa *C. × myrtifolia* and *C. ichangensis*, the yield was 0.5 and 0.6 kg/tree, respectively.

Features of growth processes characterizing citrus taxa are determined by a number of indicators: plant height, trunk diameter, growth length, total growth, etc. As a result of the measurements, it was found that the greatest length of growth was noted during the first active growth. Summer and autumn active growth was characterized by lower growth length indicators, which is associated with the consumption of part of the nutrients for fruit formation. The greatest growth length during the growing season was observed in the taxa *C. ichangensis*, *C. limon* ‘Del Brasil’, *C. maxima* ‘Sambokan’, *C. medica*, which was in the range of 20.02–23.41 cm, for the remaining taxa it was 10.33–18.32 cm (Table 4).

Plant productivity, as a rule, is influenced to a certain extent by the number of shoots, i.e. The greater the number of shoots, the greater the chance of getting a high yield. On average, the highest number of shoots was observed in the taxa *C. aurantifolia* (30 pcs.), *C. aurantifolia* ‘Foro’ (27 pcs.) and *C. × limonelloides* (27 pcs.). A low indicator (12–13 pcs.) in the number of shoots was noted for *C. × latifolia*, *C. × limetta* ‘Chontipico’ and *C. limon* ‘Del Brasil’, for other taxa it was in the range of 15–19 pcs.

Table 4. Features of growth processes of rare citrus taxa

Taxon	Annual growth length, cm	Number of shoots, pcs.	Total increase, m	Stem diameter, cm	Plant height, cm
<i>C. aurantifolia</i>	16.36	30	4.85	1.63	104.3
<i>C. aurantifolia</i> 'Foro'	17.97	27	4.85	1.85	110.4
<i>C. × latifolia</i>	13.92	12	1.72	1.76	108.3
<i>C. ichangensis</i>	23.41	19	4.45	1.76	108.6
<i>C. × bergamia</i>	17.10	15	2.51	1.80	89.0
<i>C. × limonelloides</i>	10.33	27	2.76	2.12	93.3
<i>C. × limetta</i> 'Chontipico'	16.61	13	2.16	1.81	118.7
<i>C. limon</i> 'Del Brasil'	22.00	12	2.64	2.23	129.1
<i>C. maxima</i> 'Sambokan'	20.53	16	3.22	1.77	136.5
<i>C. medica</i>	20.02	18	3.60	2.03	122.5
<i>C. medica</i> var. <i>sacrodactylus</i>	16.01	15	2.40	1.95	122.8
<i>C. × meyeri</i>	18.32	16	2.93	1.20	107.6
<i>C. × myrtifolia</i>	10.98	16	1.76	1.25	79.1
<i>NSR_{0.5}</i>	3.75	7.26	1.19	0.86	6.41

According to the degree of crown growth, rare taxa were divided into three groups:

- Taxa *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. ichangensis* have a high degree of crown growth, the total growth was 4.45–4.85 m.
- Taxa *C. × bergamia*, *C. × limonelloides*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. maxima* 'Sambokan', *C. medica*, *C. medica* var. *sacrodactylus*, *C. × meyeri* have an average degree of crown growth, the total growth is in the range of 2.16–3.60 m.
- Taxa *C. × latifolia* and *C. × myrtifolia* have a low degree of crown growth, the total growth was in the range of 1.72–1.76 m.

For taxa in which the number of shoots prevailed over the length of growth, a dense, compact crown was observed. This type of crown is typical for *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × limonelloides*, *C. × myrtifolia*. For the taxa *C. × latifolia*, *C. ichangensis*, *C. × bergamia*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. maxima* 'Sambokan', *C. medica*, *C. medica* var. *sacrodactylus*, *C. × meyeri*, a looser, spreading, lighter crown was observed. As a rule, in these taxa the internode size is larger.

With low growth intensity of *C. × bergamia*, *C. × limonelloides*, *C. × myrtifolia*, the plant height was 79.1 – 93.3 cm. Slightly higher growth intensity was observed in *C. aurantifolia*, *C. × latifolia*, *C. aurantifolia* 'Foro', *C. × ichangensis*, *C. × meyeri*, plant height was in the range of 104.3–110.4 cm, the taxa *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. maxima* 'Sambokan', *C. medica*, *C. medica* var. *sacrodactylus*, their height varied from 118.7 to 136.5 cm.

4 Discussion

The collection of citrus fruits of the Federal Research Center "Subtropical Research Center of the Russian Academy of Sciences" includes 144 genotypes, which includes a large genetic diversity of different species and varieties. Therefore, it is important to carry out various scientific work, including the study of the biological characteristics of citrus taxa, which are aimed at preserving and increasing plant biodiversity. Also, the results of this work will serve as good material for use in production, genetic and breeding programs.

5 Conclusion

The information obtained from studying the biological characteristics of citrus plants will be useful in efforts to conserve and disseminate citrus genetic resources, and will also serve as valuable materials for use in breeding programs to create new forms and thereby help increase biodiversity.

As a result of the research, the forms *C. maxima* 'Sambokan', *C. × meyeri* *C. × limetta* 'Chontipico' and *C. × limonelloides* were isolated, which can be recommended for creating plantings in open ground and cultivation structures with uncontrolled conditions in the humid subtropics of Russia. Taxa *C. aurantifolia*, *C. aurantifolia* 'Foro', *C. × limonelloides*, *C. × meyeri*, *C. × myrtifolia*, *C. × latifolia*, *C. × bergamia*, *C. × limetta* 'Chontipico', *C. limon* 'Del Brasil', *C. × meyeri*, *C. medica* var. *sacroductylus*, distinguished by its decorative qualities, can be recommended as an extension crop in demonstration areas, as well as for the design of winter gardens, terraces and interiors in various rooms.

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