Development of a new method for determining the degree of ripeness of tomato fruits with different colors of ripe fruits

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Abstract. The paper evaluates the most common sensory, physical, physicochemical and biochemical methods of determining the degree of ripeness of tomato fruits. On the example of small-fruit varieties with red, orange, yellow and brown colors of ripe fruits, an attempt was made to create a universal scale to assess the degree of ripeness of tomato fruits based on the physiological state of the fruits. The paper presents data on the quantitative content of endogenous ethylene in fruits with certain ripeness level.

1. Introduction
The degree of ripeness is the most important indicator characterizing the quality of tomato fruits. The degree of ripeness depends on the mechanical strength of the fruits, the juiciness of the pulp, the content of sugars, organic acids, dry substances, respiration intensity, and other important physiological, physical, mechanical and biochemical indicators [5]. The degree of ripeness depends on the optimal temperature and relative humidity during storage, as well as on the rate of post-harvest ripening, preservation and quality of tomato fruits after ripening, transportation or storage [4, 5]. It is known that the lower the degree of ripeness of the fruits put into storage, the better their preservation, but worse taste and other quality indicators of ripe fruits [4, 5].

Scientists in different countries of the world studied the degree of ripeness. To date, many different methods and approaches were developed to determine the degree of ripeness of tomato fruits, each of which has its own advantages and disadvantages.

In our country, in practical and scientific work with tomatoes, the degree of ripeness is usually determined sensory (visually) by changing the color of the skin and the pulp transmitted through it based on 3 of the most common scales: according to D.D. Brezhnev, V.A. Bakulina and A.V. Alpatiev [3]. At the same time, the method of D.D. Brezhnev distinguishes 3 degrees of ripeness (green, breaker and full), V.A. Bakulina – 4 (green, white, pink and red), and the most common method of A.V. Alpatiev – 5 degrees of ripeness (green, breaker, brown, pink and red).

The disadvantages of all these methods include:
- subjectivity of evaluation related to human eye features;
- blur in the concept of colors such as hoary, breaker, brown, and especially the boundaries between them;
- lack of a clear understanding of changes in the physiological state of fruits during the transition from one degree of ripeness to another;
- inability to compare the values obtained using the 3- or 4-point scales with the degree of ripeness determined on a 5-point scale;
- inability to use tomatoes with yellow, orange, brown and other (except red) colors of fruits.

The instrumental methods for determining the degree of ripeness of tomato fruits are more accurate and less subjective, however, they are far from perfect and do not solve all problems. Such methods are mostly low-performance, high-cost, and the obtained results are usually not comparable to each other. In our opinion, the most successful way to determine the degree of ripeness of tomato fruits is proposed by Dutch scientists on the basis of an 8-point color scale. For each of 8 ripeness degrees the developers set certain values of specific weight, density, content of sugars, acids, dry substances, respiration intensity and rate of ethylene release [9]. In our country in 1989, V.G. Korol proposed using a 9-point scale to determine the degree of ripeness of tomato fruits grown in the summer-autumn rotation of winter greenhouses [9]. In addition to simple verbal descriptions (as was the case with the use of 3-, 4- and 5-point scales) for more accurate and objective determination of the color of the fruits V.G. Korol suggested to use the real scale of colors by A.S. Bondartsev, which includes 105 tone shades of different colors. Each color has its own number, letter and name (for example, B-3 yellow-green, Zh-1 rusty, etc.), which allows more objectively and accurately evaluating tomatoes by the degree of ripeness, distinguishing even difficult colors and shades [1]. The disadvantages of the 9-point scale of V.G. Korol include the lack of data on at least one, and even on several indicators characterizing the physiological state of fruits of the certain degrees of ripeness.

Among the instrumental methods for determining the degree of ripeness of all climacteric fruits, the most tested and accurate is the gas chromatographic method based on determining the endogenous ethylene content in fruits [4]. Ethylene is a hormone of maturation and aging and as the fruits mature, its content in the fruits constantly increases. Due to the fact that the content of ethylene in fruits closely correlates with the degree of ripeness, its quantitative determination at different stages of maturation may serve as an objective criterion of the physiological state of fruits and characterize the degree of ripeness much more fully and more precisely than the color [2-5].

Therefore, the content of endogenous ethylene may be much more accurately and objectively judged by the physiological state of fruits than by the change in color, the content of ascorbic acid, dry substances, titratable acids and other indicators [4-8].

Currently, the method has been tested and successfully used in large fruit farms to determine the ripeness of apple and pear fruits [4]. This method has not yet been studied enough on tomatoes.

In this regard, the purpose of our study was to develop a universal ripeness scale for tomato fruits with red, yellow, orange and brown colors by physiological condition.

In our opinion, the proposed scale will combine the advantages of visual (speed, simplicity, economy and high performance) and instrumental methods (high accuracy, assessment of physiological state and exclusion of subjectivity of evaluation) to determine the degree of ripeness of tomato fruits.

2. Materials and methods
Experimental research was carried out on the fields of the Roscha farm in the laboratories of the center for collective use of scientific equipment of Michurinsk State Agrarian University and the laboratory of post-harvest technologies of I.V. Michurin Federal Research Centre.

The objects of study were small-fruit varieties of tomatoes with various colors of ripe fruits: Mini bell – red, Orange cream – orange, Plum-shaped yellow – with yellow and Black Moor – brown (Figure 1, 2).

Immediately after harvesting, the fruits were visually distributed by color to the maximum possible number of color groups for the eye. Using the scale of colors by A.S. Bondartsev [1], it was
established which color (or several colors) each sample we selected corresponds to, assigning it the number, letter and name of the corresponding color. Within 1-1.5 hours after harvesting, the fruits were delivered to the laboratory of the post-harvest technology department of the I.V. Michurin Federal Research Centre to determine their endogenous ethylene content. The content of endogenous ethylene was determined in each color group using GC-2014 “Shimadzu” gas chromatograph [4]. After quantification of endogenous ethylene content in fruits of visually different 7 color groups, they were combined into 5 degrees of ripeness. The main criterion for combining color groups into ripeness degrees was their physiological homogeneity established by the quantitative content of endogenous ethylene in fruits.

3. Results and Discussion
In tomato practice, the division into ripeness levels needs to be carried out mainly to identify the groups that best meet the needs according to the purpose. In scientific and practical work with tomatoes, 5 degrees of ripeness are usually distinguished for the following:

1. transportation to long distances or for long-term storage (according to a 5-point scale – green formed tomatoes);
2. transportation to medium distances or for average storage (according to a 5-point scale – milky);
3. transportation to short distances, or for short-term storage (according to a 5-point scale – breaker);
4. fresh consumption, holocarpous conservation and short-term sales period (according to a 5-point scale – pink);
5. direct consumption in fresh form or processing into tomato products (according to a 5-point scale – red).

The studies revealed that the varieties with red, orange, yellow and brown fruits may be easily divided into 7 well-distinguished color groups (Figure 1, 2).

Figure 1. Division of tomato varieties Noble Prince (A) and Orange Cream (B) into color groups
Figure 2. Division of tomato varieties Plum-shaped yellow (A) and Black Moor (B) into color groups

When comparing the studied varieties with the color scale of A. S. Bondartsev, we used more than 30 colors and shades, of which 24 were most often found (Table 1).

Table 1. Definition of colour coding according to A.S. Bondartsev scale

| Code | Shade                                      |
|------|--------------------------------------------|
| A-7  | bluish-greenish                            |
| B-3  | yellow-green                               |
| B-5  | red-brown                                  |
| B-6  | cream                                      |
| B-7  | olive yellow                               |
| E-6  | light yellow                               |
| E-7  | greenish-yellow                            |
| Zh-1 | rubiginous                                 |
| Zh-2 | reddish                                    |
| Zh-4 | pale terracotta                            |
| Zh-6 | light yellow                               |
| M-2  | marbled pink                               |
| M-5  | red                                        |
| M-7  | golden yellow                              |
| O-3  | orange                                     |
| O-5  | incarnate-red                              |
| P-3  | pale honey                                 |
| P-4  | orange-red                                 |
| D-2  | apricot-yellow                             |
| L-1  | smoke grey                                 |
| L-4  | grass-green                                |
| Z-3  | ochreish                                   |
| Z-7  | glaucescent-green                          |
| K-3  | pale sand                                  |
| E-7  | light yellow                               |
| L-4  | grass-green                                |
| L-1  | smoke grey                                 |
| L-4  | grass-green                                |

The quantitative determination of endogenous ethylene content in orange, brown and yellow color of ripe fruits showed that the dynamics of endogenous ethylene accumulation in them is similar to the varieties with red color of ripe fruits (Figure 3).

Figure 3. Endogenous ethylene content in tomato fruits of varying ripeness, ppm
The task of further research was to combine 7 identified color groups into 5 degrees of ripeness with different physiological state. The data shown in the table demonstrate that the endogenous ethylene content of the fruits of the first and second color groups was very low and low, respectively. Thus, in the first color group, the endogenous ethylene content ranged from 0.65 ppm (Orange Cream) to 1.06 ppm (Plump-shaped yellow) (Table 2).

**Table 2.** Endogenous ethylene content in small-fruited tomato varieties of different red colours of ripe fruits (average over 3 years)

| Color group | Noble Prince | Orange Cream | Plum-shaped yellow | Black Moor | Degree of ripeness |
|-------------|--------------|--------------|--------------------|------------|-------------------|
| 1           | 0.85         | 0.65         | 1.06               | 0.80       | 1                 |
| 2           | 2.11         | 3.07         | 7.34               | 5.94       | 2                 |
| 3           | 8.22         | 11.05        | 15.91              | 13.32      | 3                 |
| 4           | 22.16        | 28.06        | 24.43              | 23.75      | 4                 |
| 5           | 24.11        | 34.10        | 22.62              | 23.01      | 5                 |
| 6           | 15.59        | 22.75        | 20.80              | 21.42      | 6                 |
| 7           | 10.50        | 20.39        | 19.29              | 12.25      | 7                 |

In the second color group, the endogenous ethylene content increased to 2.11-7.34 ppm, which indicates some activation of physiological processes caused by the beginning of the ripening process. In terms of the quantitative content of endogenous ethylene, these color groups do not differ significantly from each other and could be combined into one degree of ripeness. However, the curve of endogenous ethylene accumulation by small fruit at ripening (Figure 3) shows that the first color group should not be combined with the second for two reasons.

First, the fruits of the 2nd color group during post-harvest ripening changed color much faster than the fruits of the 1st color group, which indicates serious physiological differences between them. Second, combining the first two color groups into one degree of ripeness will greatly complicate the allocation of indicators for the remaining 4 degrees of ripeness.

Therefore, in small and very small fruits, the ripening mechanism starts at much lower endogenous ethylene content than in medium and large-sized fruits [2, 6]. In our experiments, raising the endogenous ethylene content to a level of 2.11-7.34 ppm was sufficient for the fruits to change color faster during after-ripening and storage process. Therefore, according to their physiological state very small fruits of the second color group should be included into a separate second (or “milky”) degree of ripeness.

As further ripeness and color changes, the endogenous ethylene content in the fruits continuously increases and reaches first 8.22-15.91 ppm in the fruits of the third color group (or “brown” degree of ripeness), and then very rapidly in the fruits of the fourth and fifth color groups. In our experiments, it turned out that the fruits of the fourth and fifth color groups with an endogenous ethylene content ranging from 22.16 to 28.06 ppm and 22.62 to 34.10 ppm, respectively, had almost the same physiological condition. The endogenous ethylene content in the fruits of these groups reaches their climacteric maximum, which indicates full ripening of the fruit. In our opinion, the fruits of the fourth and fifth color group with endogenous ethylene content at the climacteric maximum should be combined into a fourth physiological group or a “pink” degree of ripeness.

The endogenous ethylene content in fruits combined in the sixth and seventh color groups gradually decreases, which indicates the beginning of the postclimacteric period or a period of fruit sleepiness. The fruits of the sixth color group with endogenous ethylene content from 14.59 to 22.75 ppm and the seventh with endogenous ethylene content from 10.50 to 20.39 ppm according to indicator values should be combined into the fifth physiological group or “red” degree of ripeness.
4. Conclusion
When dividing small-fruit tomato varieties with different colors of ripe fruits into the degrees of ripeness, it is necessary to focus not on color differences between them, but on the quantitative content of endogenous ethylene in the fruits, thus identifying the following:
- green: fruits have finished growing, the ripening process has not yet begun; the ethylene content is low ranging from 0.65 to 1.06 ppm;
- milky: beginning of the first rise in ethylene synthesis associated with the beginning of the ripening process. The ethylene content is increased to 2.11-7.34 ppm;
- brown: first peak of the endogenous ethylene release associated with the activation of ripening processes. The ripening mechanism is started, the endogenous ethylene content increases to 8.22-15.91 ppm;
- pink: second (climacteric) peak of endogenous ethylene release associated with achieving consumer ripeness of fruits. The endogenous ethylene content reaches 22.16-34.10 ppm, which corresponds to the climacteric maximum;
- red: there are processes associated with over-ripening and aging of fruits (postclimacteric period). The endogenous ethylene content is reduced to 8.50-22.75 ppm.

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