STUDIES ON THE COLORATION OF TOMATO FRUITS

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INTRODUCTION

Since demand for tomato fruits is ever increasing in recent years, the area of tomato cultivation has been extended and numerous varieties introduced. And a large number of physiological or horticultural studies on tomato plant have been carried out.[5][19]

In these studies, not only the fruit yield but the fruit quality is an important subject. Though pigment contents of fruit are considered to be the most important of all fruit qualities, the study on the pigment contents in fruits is scarce in Japan. On the other hand, many workers of the U. S. A. have studied the pigments of fruits.[1][4,8][11][13][15][17][22][23] The major pigment in mature red tomatoes is lycopene, although carotene and xanthophyll are present in small amounts.

Smith and Smith[24] reported that light is an important factor in the coloring of tomatoes, as the carotenoid content of red varieties is greatly reduced when the plants are grown in the dark room during some seasons. A marked effect of temperature upon the production of lycopene was first discovered by Duggar[3] in 1913. He described that the optimum temperature for lycopene formation is 20°C, and a temperature of 30°–37°C clearly inhibited the development of lycopene both in detached fruits and in fruits growing on the vine.

Thus, light and temperature are the important factors relating to the formation of carotenoid pigments. One of these pigments, carotene, is a precursor of vitamine A, which is so important in the nutrition of man and other animals. Accordingly, the studies of the coloring of tomatoes have a highly practical significance.

The purpose of this study conducted from 1957 to 1961 was to investigate how the coloration of tomato fruits is influenced by environmental conditions and cultivation method. 28 varieties were used. In addition researches on the growth of the plant and quality of fruits were made.

CHAPTER 1
MEASUREMENT OF PIGMENT CONTENTS OF FRUITS

Measurement of pigment contents in tomato fruits must be undertaken for studying the coloration of them. An analytical method for carotenoid pigments was established by Zechmeister and Cholnoky.[29][30] The method used in this experiment was followed to their method with a little modification.

1. Materials

The experiments were carried out in 1957 at the Agricultural Faculty, Shinshu University. Varieties used were Matsudo-Ponderosa and Kurihara. Seeds were sown in hot bed on April 1, and seedlings were transplanted in the field on June 28. Cultivation and managements were carried out according to accepted commercial practices.

2. Analytical Methods and Discussion

Zechmeister and Cholnoky[29][30] presented a method of quantitative analysis of tomato pigments. But their method was not employed in this experiment as the procedure is too complicated. Therefore, the method was improved changing adsorbents and solvents for the separation of pigments. The procedure of this quantitative analysis is shown in Figure 1, and it goes as follows.

1. Material : harvested tomato fruits were divided into halves, and 20g in fresh weight was weighed.

2. Extraction : materials, with acetone added, were crushed in a mortar, and then the solution was filtered. Extraction was repeated until the materials became thoroughly colorless. Then, the extract solution was made to 100cc in volume.

3. Calculation of chlorophyll : 100cc of the extract solution was divided into 20cc and 80cc fractions, the former used for chlorophyll analysis and the latter for the process in 4. The extinction coefficient of chlorophyll at 660m

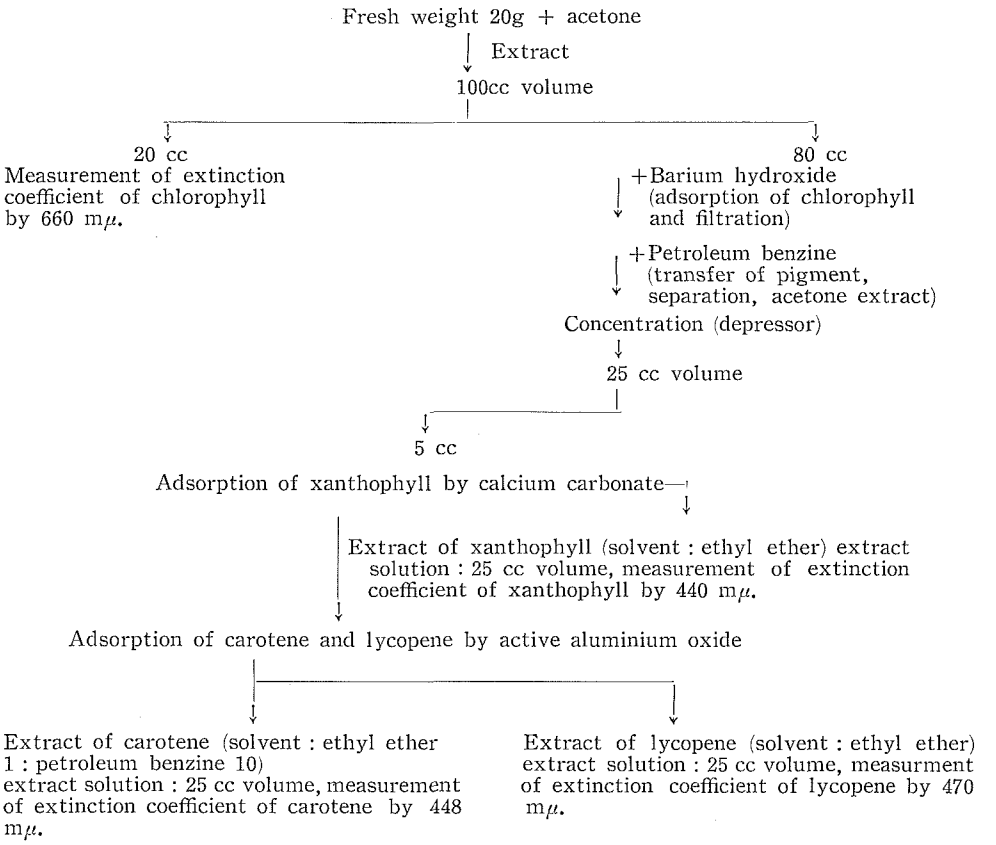


Fig. 1 Procedure of pigment analysis.

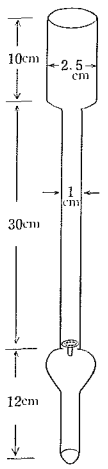


Fig. 2 Column tube.

of wave length was measured by BECKMANN DU spectrophotometer using the 1cm cell, and concentration of chlorophyll was estimated from the extinction coefficient using the standard calibration curve.

4. Separation : the 80cc fraction was added to barium hydroxide to absorb chlorophyll, and then filtered. When the filtrate was added to petroleum benzine layer. Petroleum benzine and acetone were then separated, and the former was concentrated under reduced pressure to 25cc in volume.

5. Adsorption and calculation of xanthophyll, carotene and lycopene.

(1) Xanthophyll : calcium carbonate dried at 300°C and cooled in a desiccator was packed into a column tube as shown in Figure 2. Five ml of the concentrated solution mentioned above was added to the column tube. When developed with

petroleum benzine, carotene and lycopene were almost eluted as shown in Figure 3 (a). Petroleum benzine was added until the filtrate became colorless. A yellow band formed at the upper part of the adsorbent is xanthophyll. Subsequently, ethyl ether was added to the column tube as a solvent, and xanthophyll adsorbed to calcium carbonate was eluted as shown in Figure 3 (b). The eluate was made to 25cc in volume. The extinction coefficient of xanthophyll at 440 mμ of wave length was measured by BECKMANN DU spectrophotometer using the 1cm cell, and concentration of xanthophyll was estimated from the extinction coefficient obtained using the standard calibration curve.

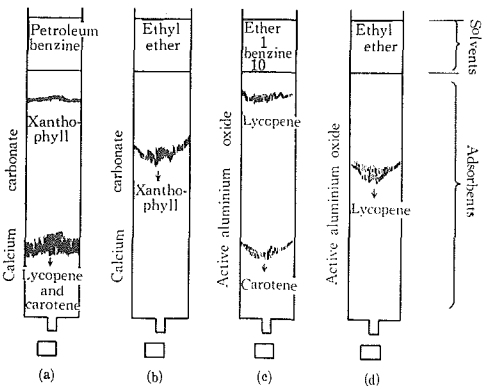


Fig. 3. Column chromatograms.
(a) (b) : xanthophyll
(c) : carotene
(d) : lycopene

(2) Carotene and lycopene : dried active alminium oxide was packed into the column tube, and the petroleum benzine eluate obtained in Step (1) was then poured into the column. Then, when developed with a solvent (ethyl ether 1 : peteroleum benzine 10) as shown in Figure 3 (c), carotene was eluted and lycopene was adsorbed to the upper part of adsorbent. The solvent previously used was added until carotene was thoroughly eluted. After carotene was eluted, ethyl ether (as a solvent) was added, as shown in Figure 3 (d), to elute lycopene. The eluates of carotene and lycopene were made to 25cc in volume respectively. The extinction coefficients of carotene and lycopene were measured at the wave lengths 448 mμ and 470 mμ by BECKMANN DU spectrophotometer using the 1 cm cell, and the concentrations of carotene and lycopene were estimated from the extinction coefficients obtained using the standard calibration curves respectively.

Although pigment contents of tomato fruits were measured by the method above mentioned, carotenoid pigments were also contained in small amount in the material for chlorophyll analysis. Accordingly, it was considered that the extinction curve of chlorophyll was more or less affected. Therefore, the result of extinction curve of each pigment measured with BECKMANN DU spectrophotometer is shown in Figures 4–7. From these figures, it is understood that the wave length 660 mμ used for the chlorophyll measurement was not influenced by the presence of other pigments : xanthophyll, carotene or lycopene. Furthermore, Figure 8 shows how the extinction coefficient of chlorophyll was influenced

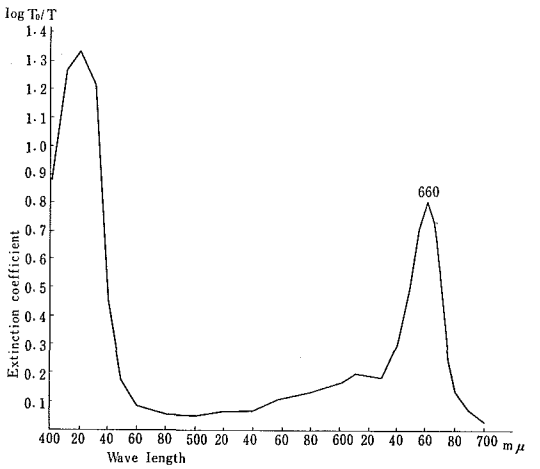


Fig. 4 Extinction curve of chlorophyll (50 ppm). (solvent : acetone 85%)

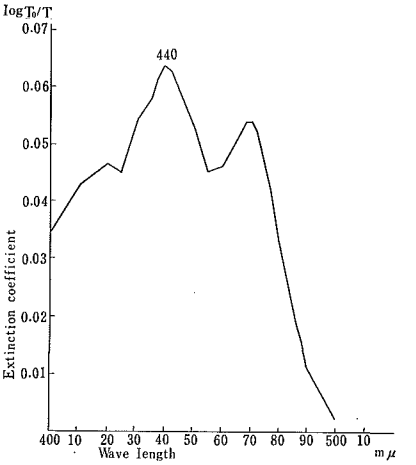


Fig. 5 Extinction curve of xanthophyll. (solvent : ether)

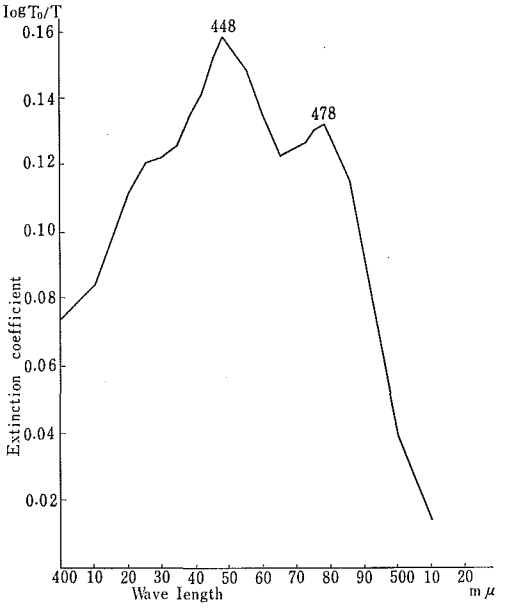


Fig. 6 Extinction curve of carotene (2.5 ppm). (solvent : petroleum benzine 10 : ethyl ether 1)

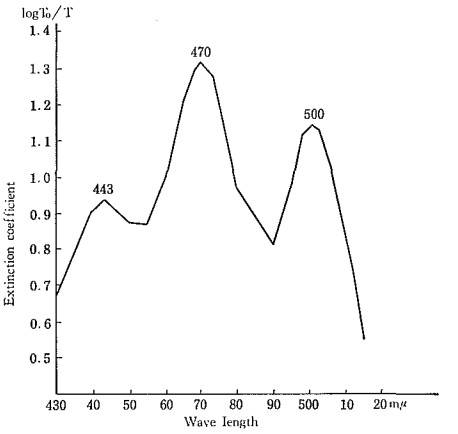


Fig. 7 Extinction curve of lycopene (25 ppm). (solvent : ether)

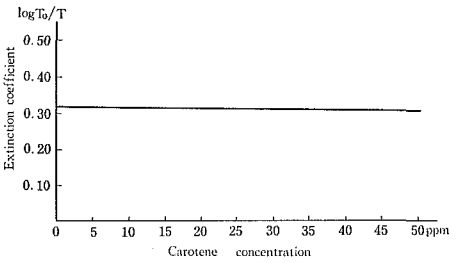


Fig. 8 Influence of carotene contents upon the extinction coefficient of chlorophyll (chlorophyll-25 ppm, wave length-660 mμ).

by carotene concentration mixed in chlorophyll solution. While the carotene concentration was varied from 0 ppm to 50 ppm, the extinction coefficient of chlorophyll differed only from 0.32 to 0.30, showing that its influence was slight. In measuring the extinction coefficient of chlorophyll, therefore, it was assumed that results of this analytical method were not much influenced by the presence of other pigment.

The wave lengths adopted for measurement of the extinction coefficient of each pigment are shown in Figures 4–7. Each wave length represents the extinction peak in the extinction curve of each pigment. Furthermore, these wave lengths show the character of each pigment when the solvent is constant.

Using the method mentioned above, pigment contents and sugar contents in fruits of the varieties, Matsudo-Ponderosa and Kurihara were analyzed. Furthermore, comparisons of the contents between immature and mature, or large and small, fruits in each variety were done. The results are shown in Table 1. It is recognized from this table that chlorophyll was contained in immature fruits, but disappeared in mature fruits. On the contrary, lycopene was not found in immature fruits, but appeared as fruits matured. Carotene and xanthophyll were contained in both immature and mature fruits, but the contents were much higher in mature fruits. Accordingly, these pigments increased as fruits matured, as lycopene. The highest in the pigment content of mature fruits was variety Matsudo-Ponderosa. That there was no difference in these pigment contents when cultivation method and management were varied is considered, as Le Rosen et al[9] pointed out, to be due to genetic character. Among mature fruits, there was difference in the pigment contents per unit weight between small and large fruits. Went et al[28] described that there seems to be a correlation between size of fruit and lycopene concent-

Table 1. Pigment and suger content of tomato fruits.

		Fresh weight g	Chlorophyll mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Lycopene mg/fresh weight 100 g	Xantho-phyll $\log T_0/T$	Total sugar mg/fresh weight 10 g	Dry matter %
Immature fruits	Matsudo-Ponderosa	62.1	12.15	0.422	0	0.057	243.0	5.9
	Kurihara	113.3	10.85	0.453	0	0.054	220.0	6.5
Mature fruits	Matsudo-Ponderosa large fruits	246.0	0	1.088	49.25	0.080	177.5	4.6
	Matsudo-Ponderosa small fruits	156.0	0	1.069	48.75	0.089	177.5	4.4
	Kurihara large fruits	367.0	0	0.656	34.25	0.069	322.5	4.6
	Kurihara small fruits	220.3	0	0.694	34.75	0.089	311.2	5.0

ration : the larger the fruit, the higher the lycopene content. Furthermore, the same workers pointed out that pigment contents of mature fruits are influenced by unknown external or internal factors but partly depend on physiological condition of the plant. As for the sugar content of immature fruits, variety Matsudo-Ponderosa is superior to variety Kurihara, but in immature fruits, this relationship is reversed.

CHAPTER 2
CHANGES OF PIGMENT CONTENTS DURING THE DEVELOPMENT OF FRUITS

The tomato fruit changes its color from green to red along with its development from setting. Red fruits are generally considered as in matured condition, but the relationship between the red color and maturity is doubtful. This experiment was carried out to observe how pigment contents of fruits change as fruits develop from flowering to maturity.

1. Materials and Methods

The experiments were carried out in 1957 and 1958 at the Agricultural Faculty, Shinshu University. Varieties used were Kurihara and Matsudo-Ponderosa in 1957, and Kurihara in 1958. The cultivation method used in both years is shown in Table 2.

Table 2. Cultivating method.

	Seeding date	Transplanting date	Nutrient * kg		
			Nitrogen	Phosphorus	Potassium
1957	April 1st	June 3rd	24	30	22
1958	March 30th	May 28th	27	26	35

* per 10 a

When harvesting materials for pigment analysis, they were selected on the basis of uniformity of fruit development. In 1957, the first flower of the second flower cluster was used. The materials were picked in variety Kurihara 25 days and in variety Matsudo-Ponderosa 19 days after flowering. In the former they were picked 6 times and in the latter 7 times. In 1958, as well as in 1957, fruits were picked 9 times from June 20 to August 23. Eight to ten fruits were picked at each harvest in both years. The materials picked were measured for fresh weight and diameter per fruit, and expressed in gram and

centimeter respectively. The method described in Chapter 1 was followed for pigment analysis, and chlorophyll, carotene and lycopene were expressed in mg per fresh weight 100 g, while xanthophyll was expressed in extinction coefficient log T_0/T.

2. Results

(1) Results in 1957 : The earliest flowering date of the flowers in the first flower cluster was June 26 in Kurihara and June 24 in Matsudo-Ponderosa, and

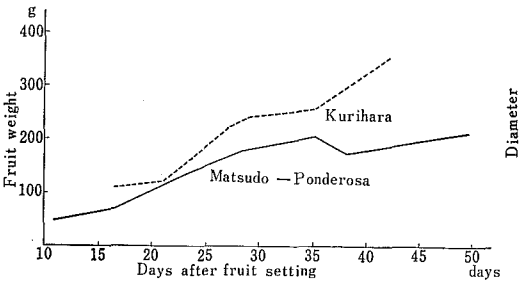
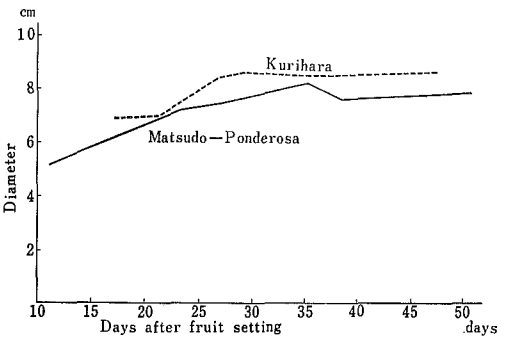


Fig. 9 (1) Development of fruit weight.



(2) Development of fruit diameter.

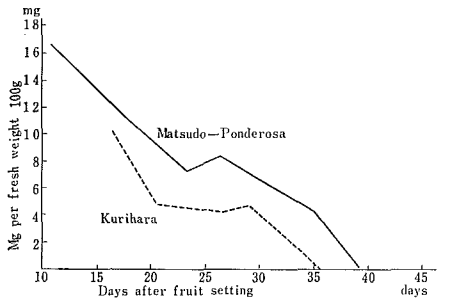
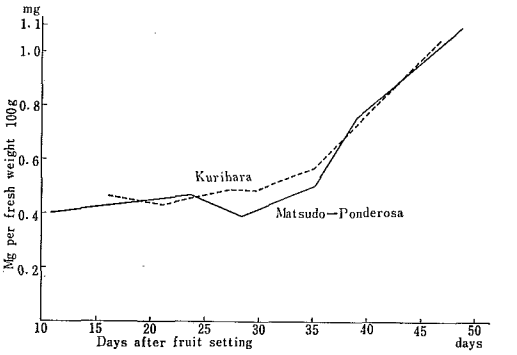
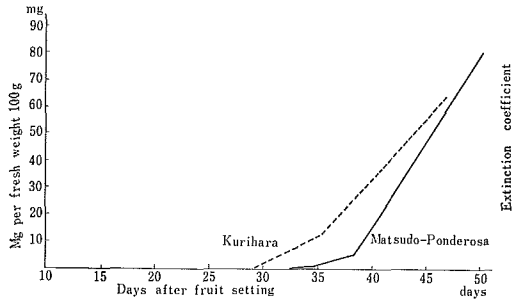


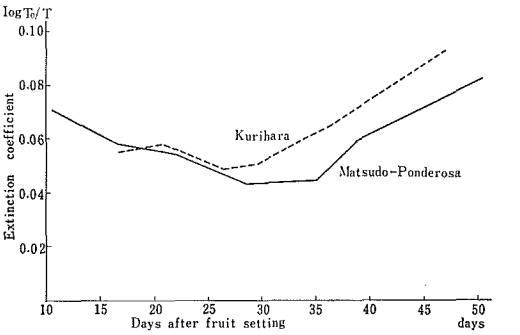
Fig. 10 (1) Changes of chlorophyll content.



(2) Changes of carotene content.



(3) Changes of lycopene content.



(4) Changes of xanthophyll content.

the earliest flowering date of the flowers in the second flower cluster was July 7 in the former and July 4 in the latter variety. Fresh weight and diameter of fruits measured are shown in Figure 9 (1) and (2). Post-flowering increases in fresh weight and diameter were larger in Kurihara than in Matsudo-Ponderosa, and the number of days from flowering to maturation was smaller in Kurihara. Accordingly, fruit development of Kurihara was more rapid than in Matsudo-Ponderosa.

Changes in chlorophyll, carotene, lycopene and xanthophyll contents are shown in Figure 10 (1), (2), (3) and (4). The chlorophyll contents of both varieties rapidly decreased with fruit development, and chlorophyll in the flower end part of fruit disappeared about 43-46 days after flowering. Disappearance of chlorophyll took place earlier in Kurihara than that in Matsudo-Ponderosa. Accordingly, it was considered that there exists a correlation between disappearance of chlorophyll and maturing of fruit. Carotene content in fruits did not greatly change till 40 days after flowering, but from 45 days after flowering the content increased rapidly. Both Kurihara and Matsudo-Ponderosa showed the same tendency. Lycopene appeared in the flower end part about 38-40 days after flowering, and rapidly increased thereafter till fruits matured. In both varieties, appearance of lycopene and disappearance of chlorophyll took place almost at the same stage. Judging from these results, some correlation may exist between appearance and disappearance of the pigments in fruits. Xanthophyll content in fruits decreased from about 18 days after flowering, and increased from 38 days after flowering, and mature fruits showed the highest xanthophyll content. Carotene, lycopene and xanthophyll contents of fruits in both varieties were the highest in mature fruits. When compared, Kurihara was higher in xanthophyll content, but lower in carotene and lycopene contents, than in Matsudo-Ponderosa.

(2) Results in 1958 : fruits of the first flower cluster whose flowering took place on June 15 were used. Fresh weight, diameter and contents of chlorophyll, carotene, lycopene and xanthophyll in fruits are shown in Table 3. Fresh weight and diameter of fruits increased with increase in the number of days after flowering. Chlorophyll content also decreased as in 1957 with fruit development, and the pigment disappeared about 50 days after flowering. Carotene content of fruit decreased till about 40 days after flowering and increased thereafter up to mature stage. Lycopene and xanthophyll contents of fruits were almost the same as in 1957.

3. Discussion

In order to examine how the pigment content in tomato fruits cultivated

Table 3. Fruit development and change of pigment contents.

Days after flowering day	Fresh weight g	Diameter cm	Chlorophyll mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Lycopene mg/fresh weight 100 g	Xanthophyll log T_0/T
5	0.83	0.72	27.81	1.027	0	0.084
15	13.62	3.25	25.63	1.027	0	0.130
25	83.00	5.75	12.19	0.500	0	0.054
35	153.90	7.06	12.50	0.385	0	0.070
40	185.60	7.27	4.50	0.225	0	0.032
45	212.40	7.98	3.30	0.450	0.718	0.044
50	287.80	8.87	0.60	0.846	8.417	0.066
55	294.60	9.00	0	1.068	43.892	0.088
60	281.30	8.86	0	1.046	54.115	0.098
63	—	—	0	1.046	56.506	0.092

by the customary method changes with fruit development, the experiments were carried out using varieties Kurihara and Matsudo-Ponderosa in 1957 and Kurihara in 1958.

It is considered that the number of days from flowering to fruit maturation is determined by the genetical characters of each variety. Both varieties, Kurihara and Matsudo-Ponderosa, used in this experiments are midripe type, but as shown in the experimental results, fruit development was more rapid and weight per fruit was heavier in Kurihara than in Matsudo-Ponderosa.

The pigment contents in fruits were more or less different in various stages from flowering to mature. Chlorophyll almost disappeared 45 days after flowering, and fruits at this stage were green except at the apical portion. With the disappearance of chlorophyll, carotene and lycopene rapidly increased. Especially, lycopene hardly appeared while chlorophyll still existed. This fact was considered to show that appearance of lycopene is regulated by existing chlorophyll. Or, disappearance of chlorophyll, and appearance or increase in concentration of carotene, lycopene, and xanthophyll, may occur when fruits pass a certain number of days after flowering, that is, the phenomenon happens only when fruits attain a certain degree of matureness, but these problems will be the subject of future study.

Xanthophyll as well as carotene was found in fruits at all stages from flowering to maturity, but decreased with decrease of chlorophyll till about 40 days after flowering, and after disappearance of chlorophyll, increased with increase of lycopene. In mature fruits, xanthophyll content was the highest. Whenever chlorophyll is present, yellow colors of carotene and xanthophyll are covered by the color of chlorophyll. As immature fruits look green, it

is therefore difficult to distinguish the colors of carotene and xanthophyll. With fruit development, chlorophyll disappeared and fruit color changed from white to yellowish red, and then carotene and xanthophyll manifested their yellow colors. On the other hand, lycopene, a red pigment, rapidly increased as fruits matured, and mixed with carotene and xanthophyll. Consequently, fruits changed the color from orange red to red as the result of mixing.

When varieties Kurihara and Matsudo-Ponderosa are compared, immature fruits of Matsudo-Ponderosa showed a brighter green color than those of Kurihara in this experiment. This phenomenon is ascribed to the fact, as shown in Figure 9, that chlorophyll contained per unit weight was more in Matsudo-Ponderosa than in Kurihara. As for the pigment contents of mature fruits in both varieties, carotene and lycopene contents were higher in Matsudo-Ponderosa than in Kurihara, but the relation is reversed for xanthophyll content. Accordingly, the contents of carotenoid pigments in mature fruits were higher in Matsudo-Ponderosa than in Kurihara, and both varieties could be distinguished by their fruit color.

In 1958, pigment contents of Kurihara were measured, but the period from flowering to the first sampling was shorter than in the experiment in 1957. There was the same tendency as in 1957 in the changes of chlorophyll, lycopene and xanthophyll contents. But carotene content in fruits slightly changed from the result in 1957. Pigment contents per unit weight and the term length required for maturing of fruits also differed. These differences were due to the fact that the second flower cluster was used in 1957 whereas it was the

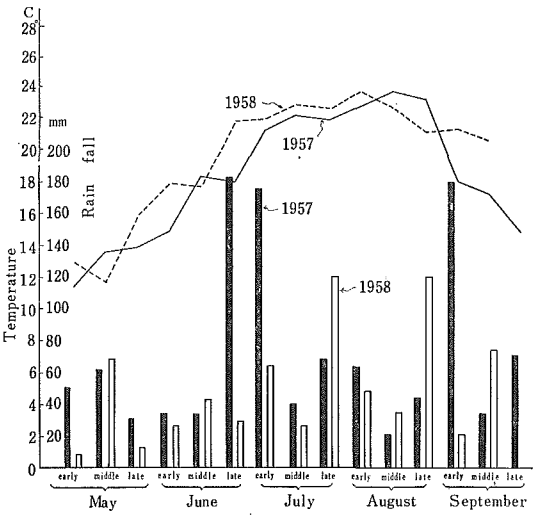


Fig. 11. Climate in 1957 and 1958.

first flower cluster that was used in 1958. Furthermore differences in nutritional conditions between both years must be taken into account. Vogel[26] and MacGillivray[16] pointed out that pigment contents of tomato fruits were influenced by temperature, and also Went et al[28] described that pigments contents were affected by physiological factors of the plant, and furthermore, Denisen[2], McCollum[12], Nettles et al[18] and Smith[25] reported that coloring of tomatoes was influenced by light. The climatic conditions when these experiments were made were different between the two years as shown in Figure 11. Accordingly, the differences in growth period and pigment contents between the two years may have been due to differences in some climatic factors.

CHAPTER 3
GROWTH, YIELDS AND PIGMENT CONTENTS OF FRUITS

In recent years, various types of cultivation around the year have been developed in districts of different climates. Therefore many varieties have been bred to meet specific requirements of each type of climate. On the table lands of Nagano Prefecture, cultivation of tomato is expanding as climatic conditions of these areas are favorable for the coloring of fruits. In this study growth habit and pigment content of tomato were investigated, using the prevailing varieties in Nagano Prefecture, Kurihara, Mitsuoka, Hikari, Aichi-tomato, Matsudo-Ponderosa and Kiyosu-Nigo and some leading varieties in other prefectures.

1. Materials and Methods

The experiments were carried out in 1958 and 1959 at the Agricultural Faculty, Shinshu University. The varieties used were Fukuju-Nigo, Furuyawase, Shinhogyoku-Nigo, Shinsei, Kurihara, Aichi-tomato, Ponderosa, Matsudo-Ponderosa, Kiyosu-Nigo, Sakae, Mitsuoka, Shinano, Kikyoiku-Ichigo, Hikari, Jubilee and Tohoku-Yongo in 1958, and Shugyoku, Shinfukuju, Fukuju-Ichigo, Fukuju-Nigo, Oogata-fukuju, Sekaiichi, Akafuku-Ichigo, Akafuku-Sango, Oogata-akafuku, Kikyoiku-Ichigo, Kikyoiku-Nigo and Jubilee in 1959. The procedure of cultivation in both years are shown in Table 4. Records were taken on plant height and number of leaves, numbers of flowers and fruits set, fruit-set coefficient, fruit yield and number of fruits per plant, dry matter coefficient of mature fruit, viscosity, pH, total acidity, sugar content of fruit, hardness and cracking condition of fruit, color of the fruit skin and pigment content of fruits. Viscosity was measured with the viscosity meter and presented in tables when needed. pH value was determined by a colorimetric method. Acidity was expressed in citric acid equivalent. Fruits were analyzed for total sugar, reducing sugar and

Table 4. Cultivation program.

Year	Seeding date	Transplanting date	Fertilizers		
			N (kg)	P_2O_5 (kg)	K_2O (kg)
1958	March 29	May 29	27.4	26.0	45.0
1959	April 1	May 28	28.0	24.0	26.0

non-reducing sugar, which were expressed as percent of dry matter. Hardness of fruit was measured by palpation in 1958, and by a hardness meter of 2 mm in diameter in 1959. Cracking in fruit was graded heavy, moderate, light and none by observation. Skin color was described according to the Color Chart.[27] Pigment content of fruit was measured by the previous method (Chapter 1), lycopene and carotene contents being expressed in mg per 100 g fresh weight, and xanthophyll content in extinction coefficient log T_0/T.

2. Results

The plant height of each tomato variety is shown in Tables 5 and 6. A difference was observed in the height of seedlings of the same age among the varieties on June 9 in 1958 and June 8 in 1959, the highest being Hikari (30.3 cm) and the shortest Tohoku-Yongo (15.8 cm) in 1958. The other varieties stand

Table 5. Plant height in each variety. (cm) 1958

Measurement date / Varietes	9/ June	16/ June	22/ June	30/ June	7/ July	14/ July	21/ July	28/ July	4/ Aug.	12/ Aug.
Fukuju-Nigo	23.0	30.5	39.8	65.5	89.0	118.2	143.0	161.5	171.0	190.8
Furuyawase	17.8	27.7	40.0	62.0	78.5	100.3	119.1	133.0	141.3	165.0
Shinhogyoku-Nigo	21.8	30.3	41.8	64.2	94.5	123.0	142.7	160.2	172.7	194.2
Shinsei	21.6	29.0	38.8	64.2	88.0	116.0	134.0	147.8	159.8	168.4
Kurihara	18.8	27.3	38.9	67.3	92.2	100.3	139.3	149.5	166.0	176.2
Aichi-tomato	18.3	27.8	39.7	64.3	89.0	113.8	130.5	146.5	159.7	178.3
Ponderosa	20.0	31.0	43.2	67.4	98.6	123.2	142.6	154.8	165.8	163.6
Matsudo-Ponderosa	22.7	32.3	43.0	70.8	98.0	124.8	148.2	171.5	194.7	207.3
Kiyosu-Nigo	14.8	22.0	30.8	51.0	75.7	101.2	119.6	133.0	137.8	158.6
Mitsuoka	20.8	28.7	37.0	60.8	81.2	102.2	117.0	138.3	152.2	162.5
Sakae	19.1	27.5	37.2	62.8	86.3	105.7	127.3	141.5	155.7	165.8
Shinano	17.2	24.5	32.5	54.5	76.8	102.0	121.8	135.2	151.5	169.8
Kikyoiku-Ichigo	28.2	37.0	48.8	77.5	102.0	123.5	141.2	153.2	171.7	189.0
Hikari	30.3	32.8	43.7	68.7	88.0	108.2	123.0	141.8	158.2	177.3
Jubilee	20.2	28.3	38.5	57.0	75.5	91.8	104.2	118.3	125.7	134.3
Tohoku-Yongo	15.8	22.8	29.0	45.8	50.8	68.8	71.8	73.8	74.8	81.8

Table 6. Plant height in each variety. (cm) 1959

Measurement date / Varieties	8/June	18/June	28/June	8/July	18/July	28/July
Shugyoku	23.4	35.7	57.5	89.2	108.0	124.0
Shinfukuju	23.0	35.6	65.9	115.5	161.3	206.3
Fukuju-Ichigo	32.1	50.0	88.6	141.9	181.7	218.9
Fukuju-Nigo*	19.9	28.2	51.9	93.0	129.1	167.3
Oogata-fukuju	27.9	42.5	75.3	115.5	143.7	171.5
Sekaiichi	27.0	42.0	73.8	121.3	155.8	182.5
Akafuku-Ichigo	25.7	39.2	68.8	110.8	134.2	158.9
Akafuku-Sango	29.2	42.9	74.0	117.2	145.4	174.9
Oogata-akafuku	32.8	50.0	85.3	140.7	183.8	227.9
Kikyoiku-Ichigo	36.7	40.0	70.5	115.7	145.0	172.4
Kikyoiku-Nigo*	19.9	29.8	54.7	95.8	122.5	149.2
Jubilee	22.1	33.9	56.8	90.1	105.2	120.0

* transplanting date : June 5

between these two varieties. At the last measurement on August 12, the order in plant height did not always agree with that in the early growth, Matsudo-Ponderosa and Shinhogyoku-Nigo being of excellent growth. In 1959 growth of Oogata-fukuju and Fukuju-Ichigo was rapid. Tohoku-Yongo in 1958 and Jubilee and Shugyoku in 1959 were shorter in plant height. Increase in the

Table 7. Number of leaves in each variety. 1958

Measurement date / Varieties	9/June	22/June	7/July	21/July	4/Aug.	18/Aug.
Fukuju-Nigo	7.3	11.2	19.0	25.0	28.8	33.2
Furuyawase	7.3	11.6	18.0	23.7	26.3	30.7
Shinhogyoku-Nigo	7.8	11.5	18.2	24.5	28.0	32.7
Shinsei	7.4	11.2	18.8	24.6	28.2	30.4
Kurihara	7.2	10.8	17.2	22.2	25.5	29.3
Aichi-tomato	7.7	10.7	18.0	23.5	27.0	31.0
Ponderosa	8.0	12.6	19.4	23.8	27.2	32.8
Matsudo-Ponderosa	7.7	12.3	16.0	23.7	28.0	32.3
Kiyosu-Nigo	6.7	9.3	15.8	22.8	25.6	30.2
Mitsuoka	8.7	12.3	18.7	23.0	27.0	29.7
Sakae	7.7	11.7	18.8	23.5	28.0	32.8
Shinano	7.2	10.2	16.3	22.0	26.0	30.5
Kikyoiku-Ichigo	8.5	12.5	19.2	24.3	28.0	31.7
Hikari	8.0	11.8	17.5	22.5	27.0	30.8
Jubilee	7.2	11.8	16.5	21.3	24.7	26.8
Tohoku-Yongo	6.2	9.8	14.0	—	—	—

Table 8. Number of leaves in each variety. 1959

Varieties \ Measurement date	8/June	18/June	28/June	8/July	18/July
Shugyoku	11.3	14.7	18.7	24.1	27.5
Shinfukuju	9.4	12.4	16.2	21.5	25.3
Fukuju-Ichigo	10.9	14.9	18.8	23.5	27.8
Fukuju-Nigo*	8.5	11.3	14.3	19.3	23.6
Oogata-Fukuju	9.0	12.5	16.4	20.5	24.4
Sekaiichi	10.1	13.4	17.0	21.4	25.5
Akafuku-Ichigo	9.4	12.9	17.1	22.1	25.2
Akafuku-Sango	8.8	12.1	15.2	20.3	24.2
Oogata-akafuku	10.2	14.1	18.3	23.0	27.2
Kikyoiku-Ichigo	9.4	13.2	17.4	21.3	24.6
Kikyoiku-Nigo*	8.2	11.1	14.5	19.5	23.1
Jubilee	8.7	11.5	15.3	18.4	19.9

* transplanting date : June 5

Table 9. The numbers of flowers and fruits, and fruit set coefficient in each variety. (per plant) 1958

Varieties \ Clusters	First flower cluster			Second flower cluster			Third flower cluster		
	flowers	fruits	fruit set coeffici. %	flowers	fruits	fruit set coeffici. %	flowers	fruits	fruit set coeffici. %
Fukuju-Nigo	7.7	5.8	75.1	6.9	6.8	98.8	9.3	5.4	58.6
Furuyawase	7.3	6.3	86.4	6.3	5.3	84.2	8.0	4.3	52.6
Shinhogyoku-Nigo	5.7	5.0	88.7	6.3	5.1	81.3	7.0	4.7	66.6
Shinsei	6.9	5.8	85.4	9.5	6.2	64.9	9.5	4.8	50.8
Kurihara	6.1	5.2	85.0	6.3	4.2	66.7	7.6	1.9	25.3
Aichi-tomato	10.0	6.0	60.0	9.9	3.6	36.1	9.8	1.8	18.8
Ponderosa	14.0	5.3	37.5	14.6	3.5	23.6	12.5	2.5	19.7
Matsudo-Ponderosa	8.3	2.9	35.4	8.0	1.5	18.8	9.8	1.9	19.1
Kiyosu-Nigo	6.5	5.2	79.5	6.1	4.3	69.9	6.8	3.4	49.9
Mitsuoka	6.3	5.6	89.3	6.4	5.3	81.9	6.5	4.1	62.8
Sakae	6.8	6.0	88.9	6.9	4.8	69.9	8.3	3.2	38.1
Shinano	5.5	5.3	95.5	7.7	4.9	64.0	7.9	3.3	42.1
Kikyoiku-Ichigo	5.8	5.3	90.0	7.9	5.1	64.2	8.3	4.4	53.5
Hikari	6.0	5.1	84.7	6.8	5.0	73.2	7.5	4.1	54.4
Jubilee	5.7	4.6	80.9	6.7	3.9	58.7	6.9	2.0	28.9
Tohoku-Yongo	5.9	4.5	76.3	5.6	3.6	65.0	6.8	3.2	47.1

Table 10. The numbers of flowers and fruits, and fruit set coefficient in each variety. (per plant) 1959

Clusters / Varieties	First flower cluster			Second flower cluster			Third flower cluster		
	flowers	fruits	fruit set coeffici. %	flowers	fruits	fruit set coeffici. %	flowers	fruits	fruit set coeffici. %
Shugyoku	10.1	10.0	98.2	10.7	10.5	97.5	11.2	10.7	95.5
Shinfukuju	7.6	5.9	77.4	6.5	5.3	81.7	8.2	5.7	69.5
Fukuju-Ichigo	7.2	6.1	84.7	8.6	6.7	77.9	10.7	6.3	58.9
Fukuju-Nigo	7.0	6.0	85.7	7.5	6.3	84.1	7.8	5.1	65.1
Oogata-fukuju	6.2	5.1	82.4	6.7	5.1	75.7	7.6	4.6	59.5
Sekaiichi	6.6	4.9	74.0	7.0	4.4	63.6	7.1	4.4	62.8
Akafuku-Ichigo	7.8	6.5	83.6	7.3	6.2	85.0	8.4	6.8	81.5
Akafuku-Sango	6.3	5.3	84.1	7.0	5.6	80.0	6.1	5.0	82.0
Oogata-akafuku	6.4	4.6	72.9	6.9	4.5	64.4	8.6	4.4	51.6
Kihyoiku-Ichigo	7.8	5.5	69.8	7.9	4.9	62.1	8.5	4.4	52.1
Kikyoiku-Nigo	6.5	4.9	75.0	8.1	5.6	68.5	7.8	4.0	51.2
Jubilee	7.0	5.9	84.1	7.1	4.3	60.9	7.7	3.4	46.4

number of leaves is shown in Tables 7 and 8. The grade order in the number of leaves did not agree with that in plant height, but a trend was recognized that the larger the plants were in height, the more leaves they had. Shugyoku was an exception, for despite its shorter plant height, this variety had more leaves. The number of flowers and fruits set are shown in Tables 9 and 10. The number of flowers in a flower cluster increased in the order of the first, second and third flower cluster in both years, while the number of fruits set decreased as the order of flower cluster was advanced. Varieties with a large total number of flowers in the three flower clusters were Ponderosa, Aichi-tomato, Shinsei and Fukuju-Ichigo in 1958, and Shugyoku and Fukuju-Ichigo in 1959. On the other hand, varieties with a small total number of flowers were Tohoku-Yongo, Mitsuoka and Akafuku-Sango. The varieties with a high rate of fruit setting were Fukuju-Nigo, Furuyawase, Shugyoku, Akafuku-Ichigo, and Fkuju-Ichigo, and those with a low rate of fruit setting were Matsudo-Ponderosa and Jubilee. The fruit-set coefficient of 50 per cent or over for each flower cluster was shown by Fukuju-Nigo, Shinsei, Kiyosu-Nigo, Mitsuoka, Kikyoiku-Ichigo and Hikari in 1958, and by all varieties in 1959. Especially, Shugyoku displayed 95 per cent or over in fruit-set coefficient for each flower cluster, the highest percentage of all. A high fruit-set coefficient of total three flower clusters was observed in Fukuju-Nigo, Shinhogyoku-Nigo, Furuyawase and Hikari in 1958, and in Shugyoku, Akafuku-Ichigo, Akafuku-Sango, Kikyoiku-Ichigo, Fukuju-Nigo, Shinfukuju, Fukuju-Ichigo and Oogata-fukuju in 1959. The varieties with lower

Table 11. The number of harvested fruits[1] and fruit weight[2] per plant. 1958

Varieties	Number of harvested fruits				Fruit weight kg			
	Large fruits	Middle fruits	Small fruits	Total	Large fruits	Middle fruits	Small fruits	Total
Fukuju-Nigo	2.1	12.9	8.8	23.8	0.60	2.52	1.11	4.22
Furuyawase	0.9	10.8	3.5	15.3	0.36	2.29	0.44	3.10
Shinhogyoku-Nigo	1.1	15.7	2.6	19.3	0.45	2.89	0.31	3.65
Shinsei	1.5	12.7	8.5	22.6	0.37	2.57	0.95	3.89
Kurihara	6.2	4.5	0.1	10.8	2.21	1.10	0.01	3.32
Aichi-tomato	6.9	3.7	0.3	10.8	2.68	1.05	0.02	3.75
Ponderosa	7.5	4.1	0.3	11.8	2.83	0.93	0.03	3.78
Matsudo-Ponderosa	6.4	1.2	1.1	8.6	3.14	0.27	0.13	3.55
Kiyosu-Nigo	2.7	11.5	0.8	15.1	0.90	2.56	0.10	3.56
Mitsuoka	1.5	12.1	3.7	17.3	0.55	2.83	0.43	3.81
Sakae	2.2	8.5	1.3	12.0	0.79	1.78	0.16	2.73
Shinano	1.9	9.8	2.4	14.2	0.66	2.05	0.30	3.01
Kikyoiku-Ichigo	3.3	11.8	2,0	17.1	1.28	2.63	0.25	4.16
Hikari	2.5	13.5	3.0	19.0	0.79	2.73	0.37	3.90
Jubilee	1.7	10.5	0.8	13.1	0.64	2.40	0.11	3.14
Tohoku-Yongo	0	3.1	14.0	17.1	0	0.49	1.35	1.84

(1) Large fruit : 300 g or over, middle fruit : 150-300 g, small fruit : 0-150 g
(2) Total yield till Sep. 20

Table 12. The number of harvested fruits[1] and fruit weight[2] per plant. 1959

Varieties	Number of harvested fruits				Fruit weight g				Weight per fruit g
	Large fruits	Middle fruits	Small fruits	Total	Large fruits	Middle furits	Small fruits	Total	
Shugyoku	0	0	65.9	65.9	0	0	2788	2788	42.3
Shinfukuju	2.0	14.5	6.2	22.6	802	3000	772	4574	202.4
Fukuju-Ichigo	0.4	13.6	19.3	33.3	128	2510	2210	4848	145.6
Fukuju-Nigo	0.6	10.6	13.4	24.6	226	1916	1485	3627	147.4
Oogata-fukuju	2.3	12.5	2.7	17.5	856	2647	331	3834	213.4
Sekaiichi	1.6	17.9	6.3	25.8	648	2344	777	3764	145.9
Akafuku-Ichigo	0.6	10.8	16.6	28.0	209	2008	2011	4228	151.0
Akafuku-Sango	2.1	13.5	3.0	18.6	730	2865	377	3972	213.6
Oogata-akafuku	6.7	13.0	1.8	21.5	2750	2849	216	5815	270.5
Kikyoiku-Ichigo	0.2	10.2	6.3	17.3	302	2106	757	3165	183.0
Kikyoiku-Nigo	4.6	8.9	1.9	15.4	1820	1906	215	4011	260.5
Jubilee	0.6	9.3	2.7	12.2	514	2094	333	2941	241.1

(1) Large fruit : 300 g or over, middle fruit : 150-300 g, small fruit : 0-150 g
(2) Total yield till Sep. 10th

fruit setting were Matsudo-Ponderosa, Ponderosa and Aichi-tomato in both years. The fruit yield and the number of fruits harvested are shown in Tables 11 and 12. The number of fruits harvested in 1958 was larger in Fukuju-Nigo and Shinsei, and was smaller for Matsudo-Ponderosa, Ponderosa, Aichi-tomato and Kurihara. In 1959, Shugyoku had the largest number of fruits harvested, 65.9 fruits per plant. In the fruit yield, Fukuju-Nigo was high in 1958, and Oogata-akafuku in 1959, while Tohoku-Yongo and Shugyoku were low. When fruit size was compared, varieties bearing mainly large fruits were Ponderosa, Matsudo-Ponderosa, Oogata-akafuku, Kikyoiku-Nigo, and those bearing mainly small fruits were Tohoku-Yongo, Akafuku-Ichigo and Shugyoku. (Weight of a fruit in Shugyoku was 50 g or less.) The fruit sizes in the other varieties were middle for the most part. Accordingly, varieties with a large number of fruits generally bore fruits of small or middle size. The result of chemical analysis of fruit is given in Tables 13 and 14. In 1958, Matsudo-Ponderosa gave the highest dry matter coefficient, 5.64%, while Jubilee gave the lowest, 4.76 %, but the coefficient in each variety was higher in 1959, 7.60% in Shugyoku and 5.45% in Shinfukuju, than in 1958. Viscosity of fruit juice was highest in Matsudo-Ponderosa, and lowest in Jubilee in 1958. In 1959, Shugyoku was the highest,

Table 13. The chemical quality of fruits in each variety. 1958

Varieties	Dry matter %	Viscosity second	pH	Acidity %	Sugars %		Cracked fruits	Hardness +	Skin* color
					Toatal sugars	reducing-sugars			
Fukuju-Nigo	4.90	11.3	4.1	0.467	33.2	31.4	none	###	No. 23
Furuyawase	5.25	14.1	4.1	0.435	28.6	25.6	few	###	23
Shinhogyoku-Nigo	5.01	11.3	4.1	0.435	28.3	26.5	middle	###	12
Shinsei	4.88	11.2	4.1	0.499	15.0	13.5	middle	###	23
Kurihara	5.44	13.2	4.25	0.532	34.4	31.4	many	##	23
Aichi-tomato	4.77	10.8	4.3	0.397	28.1	25.3	many	+	12
Ponderosa	4.49	13.1	4.35	0.315	28.9	24.7	many	+	12
Matsudo-ponderosa	5.64	14.7	4.1	0.445	37.6	32.1	middle	+	12
Kiyosu-Nigo	5.23	11.8	4.0	0.634	36.3	32.3	few	###	23
Mitsuoka	5.38	12.4	4.1	.0.544	28.3	24.2	few	####	12
Sakae	5.33	13.4	4.2	0.433	28.0	26.9	few	###	23
Shinano	5.32	11.8	4.1	0.467	25.0	22.4	many	###	23
Kikyoiku-Ichigo	5.08	11.1	4.0	0.569	25.3	23.3	middle	###	23
Hikari	4.80	12.4	4.1	0.515	33.7	30.8	middle	##	23
Jubilee	4.76	11.0	4.2	0.395	20.0	18.9	none	####	73
Tohoku-Yongo	4.82	11.1	4.1	0.445	21.8	19.3	none	###	76

* No. 12 : coral, No. 23 : salmon pink, No. 73 : sunflower yellow, No. 76 : chrome lemon. + : +, ++, +++, ++++ : from soft to hard

Table 14. The chemical quality of fruits in each variety. 1959

Varieties	Dry matter %	Viscosity second	pH	Acidity %	Hardness kg	sugars %		
						Total sugars	Reducing sugars	Non-reducing sugars
Shugyoku	7.60	14.5	4.05	0.42	0.56	33.53	33.53	0.0
Shinfukuju	5.45	11.2	4.10	0.42	0.44	35.45	35.39	0.06
Fukuju-Ichigo	5.86	10.6	3.85	0.54	0.53	34.06	34.06	0.0
Fukuju-Nigo	5.96	10.9	3.95	0.52	0.59	34.83	34.28	0.55
Oogata-fukuju	6.15	11.1	4.05	0.47	0.52	35.78	34.61	1.17
Sekaiichi	6.08	11.4	4.00	0.48	0.43	38.68	36.73	1.95
Akafuku-Ichigo	5.87	10.9	3.90	0.47	0.79	35.17	34.61	0.56
Akafuku-Sango	5.83	10.7	4.00	0.40	0.54	39.00	38.37	0.63
Oogata-akafuku	6.01	10.5	4.05	0.40	0.47	37.39	35.39	2.00
Kikyoiku-Ichigo	6.02	11.0	3.95	0.50	0.41	37.56	36.00	1.56
Kikyoiku-Nigo	6.12	11.0	4.00	0.32	0.32	36.74	35.17	1.57
Jubilee	6.67	11.8	4.10	0.56	0.56	31.89	30.28	1.61

and Oogata-akafuku was the lowest, in the viscosity. In all the varieties, the larger the dry matter coefficient, the higher the viscosity of fruit juice. The pH value of fruit juice did not differ so much among the varieties. (Ponderosa had the highest value of 4.4, while Kiyosu-Nigo and Kikyoiku-Ichigo had the lowest value of 4.0 in 1958. In 1959, Shinfukuju and Jubilee had the highest value of 4.1, and Fukuju-Ichigo had the lowest value of 3.85.) The acidity of fruit juice was calculated as equivalent of citric acid. In varieties with high pH values, the acidity was low, while in varieties with low pH values, the acidity was high both in 1958 and 1959. Total sugar and reducing sugar contents of Matsudo-Ponderosa and Kiyosu-Nigo were high, and were low in Jubilee and Tohoku-Yongo in 1958. In 1959, they were high in Akafuku-Sango and Sekaiichi, and low in Jubilee and Shugyoku. Among the varieties observed in 1958, Jubilee, Tohoku-Yongo and Fukuju-Nigo produced no cracked fruits, while Kurihara, Aichi-tomato, Ponderosa and Shinano produced many. On the hardness of fruit, Jubilee and Mitsuoka gave harder, and Aichi-tomato, Ponderosa and Matsudo-Ponderosa gave softer fruits in 1958. In 1959, Akafuku-Ichigo produced the hardest and Kikyoiku-Nigo produced the softest fruits. It appeared that larger fruits were generally soft, while smaller fruits were hard. The fruits skin contained pigments. The skin of Tohoku-Yongo and Jubilee fruits had a deep yellow color, and the skin of fruits of the other varieties was coral or salmon pink. The pigment content of matured fruits is shown in Tables 15 and 16. In 1958, Kikyoiku-Ichigo contained 57.7 mg of lycopene per 100g fresh weight, followed by Furuyawase, Fukuju-Nigo and Kiyosu-Nigo. Jubilee gave the lowest lycopene content. In 1959, the lycopene content of Jubilee was also

Table 15. The pigment contents of fruits in each variety. 1958

Varieties	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthophyll $\log T_0/T$
Fukuju-Nigo	53.00	1.39	0.139
Furuyawase	56.00	1.37	0.135
Shinhogyoku-Nigo	46.05	1.31	0.125
Shinsei	44.00	1.26	0.127
Kurihara	45.60	1.14	0.104
Aichi-tomato	48.45	1.12	0.095
Ponderosa	45.45	1.19	0.110
Matsudo-Ponderosa	47.10	1.18	0.109
kiyosu-Nigo	45.00	1.03	0.127
Mitsuoka	48.50	1.19	0.124
Sakae	44.80	1.02	0.101
Shinano	50.50	1.02	0.108
Kikyoiku-Ichigo	57.50	1.26	0.122
Hikari	48.50	1.23	0.125
Jubilee	2.41	—	—
Tohoku-Yongo	37.00	1.61	0.158

Table 16. Pigment contents of fruits in each variety. 1959

Varieties	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthopyll $\log T_0/T$
Shugyoku	62.19	2.29	0.138
Shinfukuju	52.81	1.07	0.105
Fukuju-Ichigo	52.50	1.10	0.120
Fukuju-Nigo	62.40	0.94	0.096
Oogata-fukuju	70.00	0.85	0.095
Sekaiichi	58.75	0.84	0.118
Akafuku-Ichigo	50.25	1.20	0.119
Akafuku-Sango	66.25	1.10	0.103
Oogata-akafuku	69.07	1.20	0.108
Kikyoiku-Ichigo	58.90	0.98	0.110
Kikyoiku-Nigo	63.85	0.92	0.114
Jubilee	3.25	—	0.085

the lowest; but the other varities (especially, Oogata-fukuju, Oogata-akafuku and Akafuku-Sango) contained more lycopene than in 1958. Kikyoiku-Ichigo did not show a difference in the content between the years. The lycopene content of this variety was 58.9 mg per 100 g fresh weight. As for the carotene content, there was little difference among varieties, but Shugyoku had the highest content of 2.295 mg per 100 g fresh weight in 1959, and Tohoku-Yongo had

1.61 mg in 1958. Sekaiichi had the lowest of 0.845 mg. The varietal difference in the content of xanthophyll was not significant between both years, but Tohoku-Yongo had the highest content of extinction coefficient 0.158 and Jubilee had the lowest of extinction coefficient 0.085.

3. Discussion

Under the same environmental conditions, 16 varieties in 1958 and 12 varieties in 1959 were observed for fruit characters, and compared with Kurihara, Matsudo-Ponderosa, Mitsuoka, Hikari and Aichi-tomato, leading varieties in Nagano Prefecture.

As for the plant growth, Fukuju-Nigo and Shinhogyoku-Nigo were tall in 1958, and Fukuju-Ichigo, Shinfukuju and Oogata-fukuju were tall in 1959. As these varieties are F_1 hybrid, the results must have been due to the hybrid vigor or genetic character. But as Tohoku-Yongo is of self-topping, it was natural that its plant growth should have been restrained. Shugyoku and Jubilee showed little internode growth : accordingly, these varieties were smaller in plant height than the other varieties. Plant growth and the number of leaves do not always show a parallelism in any variety, and there is a large discrepancy between internode growth and the number of leaves. Matsudo-Ponderosa, Kurihara, Kikyoiku-Ichigo, Oogata-akafuku and Shinfukuju belong to a group with larger internode growth, and Jubilee, Kiyosu-Nigo, Furuyawase and Shugyoku to the other group with smaller internode growth. Increasing the number of clusters is preferable to increasing the plant height for obtaining a good yield. From this point of view, Kiyosu-Nigo and Shugyoku are typical varieties of good yield. It was observed with these varieties in both years that the number of flowers increased but the rate of fruit-set decreased, resulting in a decrease of the fruit-set coefficient in higher flower clusters. Fujii et al[5] reported that decrease of photosynthesis caused by decreasing light intensity resulted in more flower drops. Oka[19] observed that the flower drop was enhanced by abnormality of division in pollen mother cells at high temperatures. It was also recognized that flower drop was influenced by the weather condition during the growth period of plants. Climatic factors during this experiment are shown in Figure 12, which shows that flower drop did not increase when the temperature was high. It was estimated, however, that changes in the climate influenced the flower drop in the first, second and third flower clusters from the middle of June to the end of July. It is also possible that, since no thinning of clusters was practiced, nutrients in plant each with a single stem concentrated so much to the first flower cluster, that only a little was transported to the second and third clusters, increasing their flower drops. Especi-

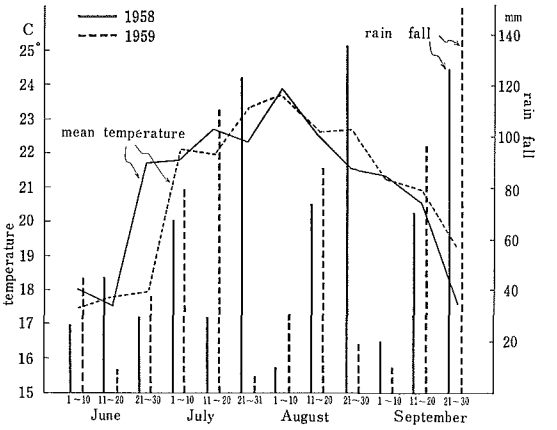


Fig. 12. Temperature and rain fall in 1958 and 1959.

ally, Matsudo-Ponderosa, Ponderosa, Aichi-tomato, Oogata-akafuku, Oogata-fukuju, Kikyoiku-Ichigo and Kikyoiku-Nigo produce fruits of large size, but their rates of flower drop are high. In varieties of small fruit size, especially Shugyoku, the number of fruits set was almost equal to the number of flowers, and the fruit set coefficient was 97 per cent or over, but the weight per fruit was 50 g or less in Shugyoku. The fruit yield in each variety depends on the number and size of fruits. As is shown in Tables 9, 10, 11 and 12, varieties Ponderosa, Matsudo-Ponderosa, Kurihara, Aichi-tomato, Oogata-fukuju, Oogata akafuku and Kikyoiku-Nigo bearing large fruits had fewer fruits, but their yield was as large as that of the other varieties. These varieties were of the so-called fruit weight type. In 1959, Shugyoku had a larger harvest in terms of the number of fruits, and a lower fruit weight than any other varieties. Accordingly, it was clearly recognized that weight per fruit influenced the yield. Fukuju-Nigo, Hikari, Kikyoiku-Ichigo, Shinsei and Shinfukuju, Fukuju-Ichigo, Akafuku-Ichigo, Oogata-Akafuku, Kikyoiku-Nigo were varieties with high yield. In some of these varieties, however, fruit weight was small but the total weight of harvested fruits was great. Therefore, they may be called varieties of fruit-number type. In processing of tomato fruits, that is, for their havest and preparation, a variety of high yield with fruit of large size is economical for harvest and preparation, as less labour is required. Accordingly, varieties Ponderosa, Matsudo-Ponderosa, Aichi-tomato, Kurihara, Oogata-akafuku, Oogata-fukuju, Kikyoiku-Ichigo and Kikyoiku-Nigo are appropriate for processing. The district of cultivation shown in Figure 12 is a tableland where growth term is shorter than in other districts. A high yield in a short

period may be expected by growing early varieties. The early ripe varieties used in this experiment were Fukuju-Nigo, Shinsei, Furuyawase, Kiyosu-Nigo, and Fukuju-Ichigo, Shugyoku, Akafuku-Sango, Akafuku-Ichigo. These varieties were higher in the fruit set coefficient than the other varieties. Early ripe varieties needed fewer days from flowering to maturity, and the numbers of their fruits harvested were large. But fruits these varieties produced were small as a whole. The varieties that produced mainly large fruits showed a low fruit setting, and their growth terms were generally long.

Differences were observed in some chemical qualities of fruit among the varieties, and demand for the qualities would be different according to how fruits are utilized. Varieties bred in recent years are very profitting for both table use and processing. In any case, fruits with large content of solid matter, high dry matter coefficient, and high viscosity of fruit juice are preferable. From these view points, Furuyawase, Kurihara, Matsudo-Ponderosa, Sakae, Mitsuoka, Shugyoku, Oogata-fukuju and Jubilee are recommendable. On the other hand, a variety whose fruits contain high percentages of sugar and organic acid has high marketability, because they have a good taste. In this respect, Kiyosu-Nigo, Matsudo-Ponderosa, Fukuju-Nigo, Hikari, Sekaiichi, Kikyoiku-Ichigo, Oogata-fukuju are recommended. On the cracking and hardness of fruit, in general, varieties producing large fruits gave softer fruits. On the other hand, cracking is less in varieties with fruits of small or middle size, and the flesh of such fruits is hard. Cracked fruits are not marketable, and soft fruits are difficult for storage. Accordingly, in case of shipping, the varieties with small and middle fruits are beneficial. As for coloration of fruits, it is important for processing that whole fruits are uniformly colored. In this experiment, all varieties except Kurihara were of good coloring. The external color of fruit was often changed according to the content of the pigments in the pericarp. Especially, Tohoku-Yongo, Jubilee, Akafuku-Ichigo, Akafuku-Sango, Oogata-akafuku and Shugyoku showed a deep yellow color in the pericarp, while in the other varieties the pericarp was light red. It was considered that pigmentation of the pericarp was of genetic character.

It was also considered that the pigment content in the flesh is genetically controlled, and the content was generally high in F_1 hybrids. The correlation between fruits weight and pigment content was not observed. Though pigment content of fruits is influenced by light and tempererature, this was out of question in this experiment as plants were cultivated under uniform environmental conditions. It was interesting that fruits contained more pigment in F_1 hybrids. But between 1958 and 1959 climatic conditions differed, and the pigment content of fruit was larger in 1959 than in 1958.

CHAPTER 4
EFFECT OF ENVIRONMENT ON THE PIGMENT CONTENTS OF FRUITS

SECTION 1. EFFECTS OF LIGHT ON THE PIGMENT CONTENTS OF FRUITS

Many authors[10][14][18][20] have studies how tomato fruits from flowering to maturity are influenced by light. Smith[25] reported that, fruits grown in complete light exclusion have a lower carotenoide content in the skin and the flesh than that grown under normal light conditions using var. Bonnny Best, Albino and Golden Queen. McCollum[12] pointed out that exposed fruits, although high in chemical component, may be low in total carotenoides, especially when high temperatures are prevailing. Although these studies were conducted with the fruits picked off from the plant, they show that light influenced the pigment content of fruits. In the present experiment were examined the effects of light on the contents of pigment and sugar in the fruits on the plant.

1. Materials and Methods

The experiments were carried out in 1958 at the Agricultural Faculty, Shinshu University. The variety used was Kurihara. Seeds were sown in hot bed on March 28, and young plants were transplanted to the field on May 29 51 cm apart in 90 cm rows. The fertilizers applied were N : 27.3 kg, P : 25.9 kg and K : 45.6 kg per 10 a. The customary method was followed for cultivation.

In order to test the effect of light, the first flower clusters that flowered on June 16 were selected. Some fruits were exposed to sunlight (exposed fruits) and some were shaded by leaves (shaded fruits). The materials were sampled 8 times from 25 to 63 days after flowering. Each time 6 fruits were sampled in both treatments. With the exposed fruits, immature ones (sampled 25 days after flowering) and mature ones (sampled 60 days after flowering) were cut into the flower-end and stem-end parts, and each part was analyzed for pigment and sugar contents. Furthermore, the exposed fruits sampled 25 and 60 days after flowering were divied into exposed and shaded parts, and each part was analyzed for pigment contents.

The pigment contents were measured by extracting chlorophyll, carotene, lycopene and xanthophyll with the method previously described. The contents of chlorophyll, carotene and lycopene were expressed in mg per 100 g fresh weight, and the content of xanthophyll in extinction coefficient log T_0/T.

Analysis of sugar contents was conducted by the Bertrand method for total, reducing and non-reducing sugars, and the results were expressed in percentage on the dry matter basis.

2. Results

Differences in chlorophyll, carotene, lycopene and xanthophyll contents between the exposed and the shaded fruits are shown in Figs. 13, 14, 15, and 16. The chlorophyll content in exposed fruits was higher than in shaded fruits. Both showed the same decreasing tendency till the disappearance of chlorophyll. Accordingly, the time of disappearance was earlier in the shaded than in the exposed fruits. But, lycopene appeared at the same time — 45 days after flowering — in the exposed and the shaded fruits, and its content rapidly increased as the fruits grew to maturity. Exposed fruits had more lycopene than shaded fruits till 55 days after flowering, but 60 or 65 days after flowering, the latter contained more lycopene than the former. Therefore, red color of mature

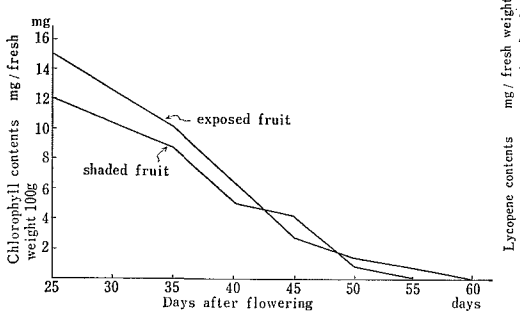


Fig. 13. Difference of chlorophyll contents.

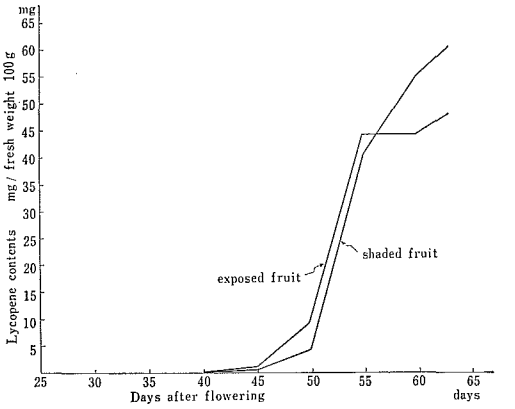


Fig. 14. Difference of lycopene contents.

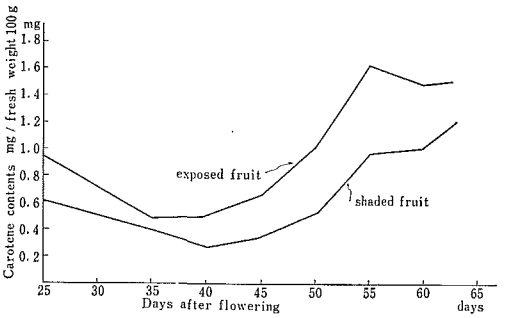


Fig. 15. Difference of carotene contents.

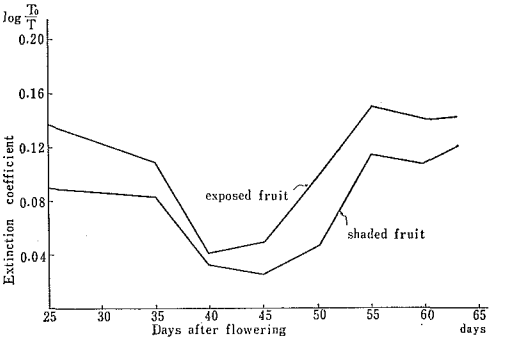


Fig. 16. Difference of xanthopyll contents.

Table 17. Difference of sugar contents in tomato fruits.

Days after flowering	Treatment	Reducing sugars	Non-reducing sugars	Total sugars
		%	%	%
15	exposed	9.68	2.75	12.43
25	exposed	18.16	1.70	19.76
	shaded	19.19	2.01	21.20
35	exposed	26.21	2.46	28.67
	shaded	26.21	1.53	27.74
40	exposed	25.92	2.11	28.03
	shaded	25.33	1.21	26.54
45	exposed	27.14	2.13	29.27
	shaded	25.61	1.53	27.14
50	exposed	33.21	2.50	35.71
	shaded	29.83	2.47	32.30
55	exposed	28.32	1.96	40.28
	shaded	36.35	2.89	39.24
60	exposed	38.94	0.97	39.91
	shaded	41.22	4.60	45.82

fruits was more distinct in shaded fruits than in exposed fruits. Carotene content was always higher in exposed fruits than in shaded fruits throughout the period of measurement, 25 to 63 days after flowering. Difference in the carotene content gave the same tendency as the difference previously mentioned (Chapter 2). Both xanthophyll and carotene were always more in quantity in exposed fruits than in shaded fruits, and fluctuation of their contents up to maturity of fruits showed the same tendency as that previously mentioned. Difference in the contents of reducing, non-reducing and total sugars in exposed and shaded fruits are shown in Table 17. Reducing and total sugars in each treatment increased as the fruits grew to maturity, reaching the maximum 60 days after flowering. But the content of non-reducing sugar showed little fluctuation. Reducing and total sugars were contained more in exposed fruits till 55 days after flowering, but on the 60th day of flowering, the contents of these sugar were higher in shaded fruits. The content of non-reducing sugar till 55 days after flowering differed little between exposed and shaded fruits, but 60 days after flowering, exposed fruits had a lower cotent of non-reducing sugar than shaded fruits. 60 days after flowering or later, there appeared more tainted fruits in exposed than in shaded fruits.

Pigment and sugar contents of the flower-end and the stem-end parts in exposed fruits 25 and 60 days after flowering are shown in Table 18. Fruits of 25 days after flowering were higher in the content of chlorophyll in the stem-end part, where the contents of carotene, xanthophyll and sugar were as high as that of chlorophyll. But in matured fruits of 60 days after flowering, lycopene and sugar contents were higher in the flower-end part than in the stem-end

Table 18. Pigment and sugar contents in different portions of tomato fruits.

Days after flowering	Parts	Chlorophyll mg/fresh wt. 100 g	Lycopene mg/fresh wt. 100 g	Carotene mg/fresh wt. 100 g	Xanthophyll log T_0/T	Reducing sugars %	Non-reducing sugars %	Total sugars %
25	flower-end	12.18	0	0.55	0.058	18.61	0.84	19.45
	stem-end	17.31	0	1.04	0.134	18.61	2.28	20.89
60	flower-end	0	47.19	1.03	0.122	38.19	2.69	40.88
	stem-end	0	33.42	1.42	0.137	32.59	1.24	33.83

Table 19. Comparison of pigment contents between exposed and shaded sides of tomato fruits.

Days after flowering	Parts	Chlorophyll mg/fresh wt. 100 g	Lycopene mg/fresh wt. 100 g	Carotene mg/fresh wt. 100 g	Xanthophyll log T_0/T
25	exposed side	18.44	0	0.95	0.098
	shaded side	15.32	0	0.63	0.078
60	exposed side	0	39.08	1.48	0.146
	shaded side	0	40.38	1.37	0.119

part, though carotene and xanthophyll contents were higher in the stem-end part. The pigment contents in the exposed and the shaded sides of the exposed fruits of 25 and 60 days after flowering are shown in Table 19. In this case also, chlorophyll, carotene and xanthophyll contents 25 days after flowering were higher in the exposed side than in the shaded side. In the fruits of 60 days after flowering as well as in those of 25 days after flowering, carotene and xathophyll contents were higher in the exposed side, but lycopene content was slightly higher in the shaded side. From these experimental results, it was estimated that pigment and sugar contents in fruits are influenced by sunlight.

3. Discussion

These studies were carried out to ascertain the effect of sunlight on the contents in tomato fruits.

Chlorophyll content in fruits exposed to sunlight was higher than in shaded fruits as shown in Table 14. As chlorophyll is produced under sunlight, it is natural that exposed fruits should have more chlorophyll than shaded fruits. The difference in chlorophyll content between exposed and shaded fruits was maintained till the disappearance of chlorophyll from fruits. Furthermore, the period during which fruits contained chlorophyll was longer in exposed fruits, and shaded fruits were lighter in color. But lycopene appeared in exposed and shaded fruits at the same time. Its amount rapidly increased up to the 55th day after flowering, when exposed fruits had more lycopene, but its content

became higher in shaded fruits thereafter. It was considered that lycopene appeared when a given period of time had passed after flowering. Namely, appearance of lycopene took place when the fruits reached maturity, whether they were exposed to sunlight or not. Vogele[26] reported that the optimum temperature for lycopene formation in tomato fruits was 24°C, and lycopene was not formed at 30°C or above. Denisen[2] pointed out that red tomato fruits covered with leaves during the growing season were deeper in red color than fruits exposed to sunlight. Also in this experiment, fruits shaded for 60 days after flowering had a higher lycopene content than exposed fruits. This phenomenon was interpreted that fruit temperature lowered by shading raised the lycopene content. A similar result was reported by Duggar[3]. The carotene content of exposed fruits was higher than that of shaded fruits either in immature or in mature fruits. McCollum[10] reported that the tomato fruits exposed to sunlight during the growing season were high in the content of total carotenoide and carotene, which is in agreement with the results of this experiment. At the same time, xanthophyll included in carotenoide pigment in exposed fruits was higher in content than in shaded fruits. Sugar content of these exposed and shaded fruits from their immature to mature stage, was analyzed. The contents of reducing and total sugars in both exposed and shaded fruits increased three times or over on the dry matter basis 60 days after flowering. Maturity of fruits was ascertained by their sugar contents, and increase of sugar contents in fruits was accompanied by increase of carotenoide contents. Exposed fruits had more reducing and total sugar 55 days after flowering than shaded ones. It is presumed from this result that metabolism in fruits was activated by exposure to sunlight, thus increasing sugar content, and sugar accumulation in fruits stimulated fruit growth. Matured shaded fruits of 60 days after flowering had more sugar than exposed fruits. This phenomenon must be considerd to be due to other factors. The content of non-reducing sugars showed no seasonal changes during the process of maturity, and between exposed and shaded fruits was found only a small difference.

In exposed fruits, the contents of chlorophyll, carotene and xanthophyll were higher in the stem-end part than in the flower-end part of immature fruits, and sugars as well as pigments were more in quantity in the stem-end part. It is reasonable to presume that the stem-end part was exposed more to sunlight than the flower-end part as previously mentioned. Mature fruits of 60 days after flowering had higher contents of carotene and xanthophyll in the stem-end part than in the flower-end part, but lycopene and sugars were more in the flower-end part than in the stem-end part. No sunlight was probably needed for lycopene production. When the exposed side was compared with the

shaded side in exposed fruits, contents of chlorophyll, carotene and xanthophyll 25 days after flowering were higher in the exposed side of the stem-end and the flower-end parts than in the shaded side, but with the fruits of 60 days after flowering, carotene and xanthophyll contents were higher in the exposed side, and lycopene was more in the shaded side.

From the results obtained in the previous experiments, it was recognized that the amounts of chlorophyll, carotene and xanthophyll were increased by exposure to sunlight though some fluctuation took place in the process of fruit development. Though lycopene content increased under sun light, it seemed that temperature is the most important factor. Of the carotenoide pigments contained in matured fruits, the proportion of lycopene is 75–85 per cent according to Went et al[28], while Kurihara variety used in this experiment had 85 per cent of lycopene. Accordingly, in order to promote good coloring in fruits, it is necessary to increase the proportion of lycopene among carotenoide pigments.

SECTION 2. CHANGES OF PIGMENT CONTENTS IN BAGGED FRUITS

In the previous study, lycopene content in fruits covered with leaves was found to be higher than in fruits exposed to sun light. This experiment was carried out to ascertain that the pigment contents are influenced by light, covering fruits with colored cellophane bags or colored vinyl bags. In addition some chemical quality and chlomoplasts of fresh cells were observed.

1. Materials and Methods

The experiments were carried out at the Agricultural Faculty of Kyoto University and of Shinshu University in 1958.

(1) Experiment at Kyoto University

Oogata-Fukuju tomato plant seeded on February 20 was transplanted to field on April 29. Fruits of green mature stage were harvested from each flower cluster on July 7, and on the same day they were covered with colored cellophane bags and each fruit was allowed to mature in a glasshouse of phytotron. Each treated fruit was analyzed on August 1 following the previous method for lycopene, carotene and xanthophyll contents.

Aichi-tomato seeded on May 2 was transplanted, and fruits of green mature stage were covered with red, green, blue and transparent cellophane bags on August 11. Then fruits bagged with cellophane were analyzed for pigment contents. Lycopene and carotene were expressed in mg per fresh weight 100 g, and xanthophyll was expressed in extinction coefficient log T_0/T. In Aichi-tomato and Jubilee seeded on May 2, fruits set on August 4 and 5 were har-

Table 20. Method of bagging, storage temperature and number of fruits sampled.

Storage temperature / Treatment	10 °C Artificial light	20 °C Artificial light	20 °C Artificial light +natural day light	30 °C Artificial light + natural day light	25°C ~ 27°C	15°C
Red cellophane bag	3	3	3	3	—	—
Green cellophane bag	3	3	3	3	—	—
Blue cellophane bag	3	3	3	3	—	—
Black cellophane bag	3	3	—	3	3	3
Control	3	3	3	3	—	—

vested on September 12, and chlomoplasts contained in flower-end part, outer part and core of these fruits were observed.

(2) Experiment at Shinshu University

Variety Kurihara seeded on April 1 was tansplanted to field on May 28, and the second flower cluster was used in the experiment. The number of flowers in the second flower cluster was restricted to 3. When the third flowers were set, the second flower clusters were bagged with transparent, white, red and black vinyl on July 5 as shown in Figure 17. Control fruits were not bagged. Culture and management were conducted in the customary manner.

During the experiment, light intensity and temperature in bags of each treatment lot were measured daily for an average of 5 days.

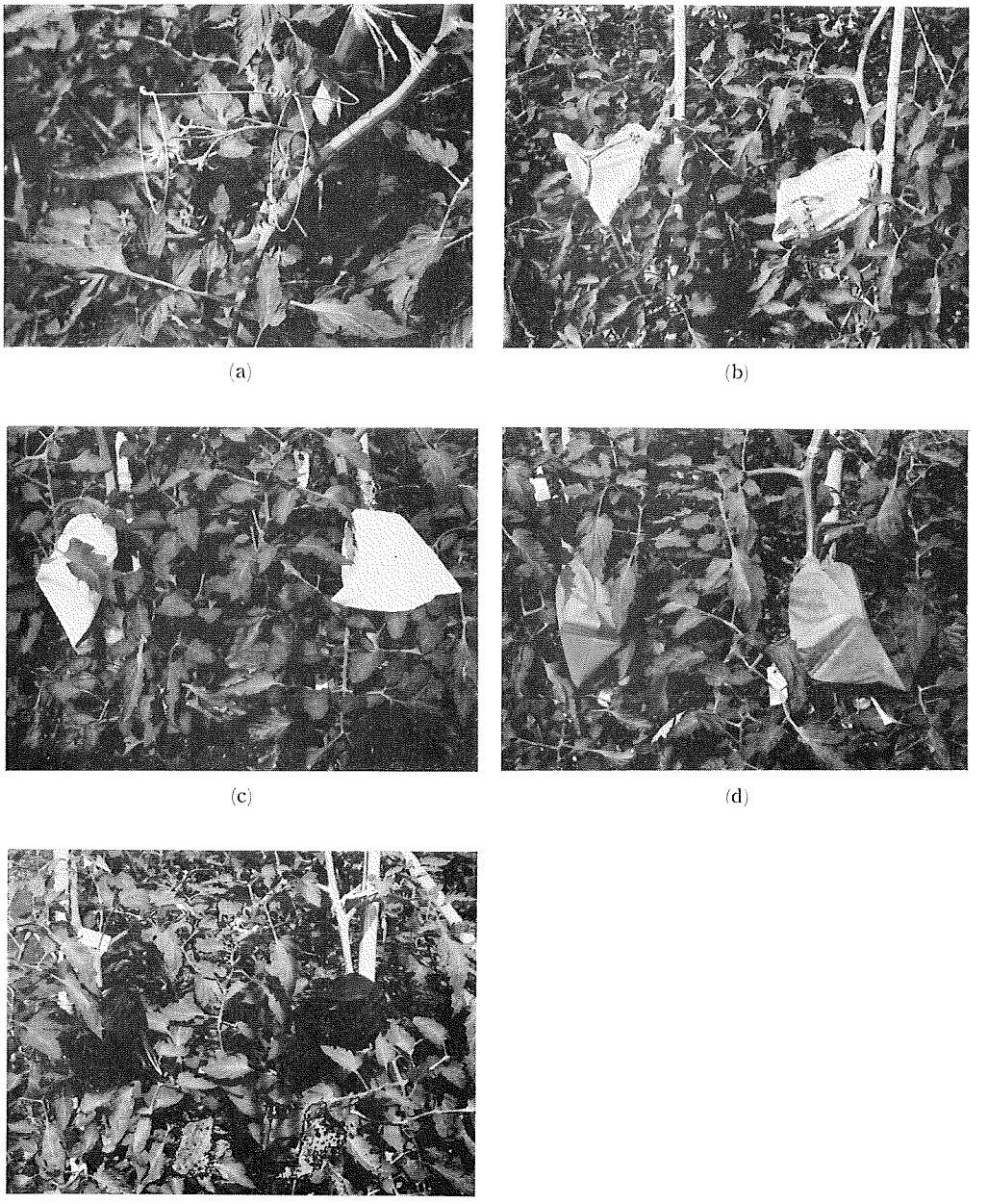
Fruits from flowers that bloomed on June 16 were bagged with vinyl 35 days after flowering, and then these fruits were harvested on August 11 and analyzed for some chemical substances.

Pigment contents in fruits covered with various bags in the former experiment were measured 35 days and 60 days after flowering, and in the latter experiment fruits harvested 55 days after flowering which had been bagged with vinyl since 35 days after flowering were also analyzed. Furthermore, fruits bagged with black vinyl till 35 days after flowering were harvested and stored at 21°–25°C (room temperature). Also these fruits were analyzed for pigment contents. Chlorophyll, carotene and lycopene were expressed in mg per fresh weight 100 g, and xanthophyll was expressed in extinction coefficient log T_0/T.

2. Results

(1) Result at Kyoto University

Green mature fruits of Oogata-Fukuju were harvested, and bagged with colored cellophane. Pigment contents of fruits measured after they were stored at each temperature are shown in Table 21. They varied depending on the color of cellophane bags. Though these stored fruits were observed to be at



(a) (b)

(c) (d)

(e)

Fig. 17. The method of bagging
(a) supporter of bag
(b) transparent bag
(c) white bag
(d) red bag
(e) black bag

Table 21. Effects of storage temperature and bagging with colored cellophane on the development of pigment in tomato fruits.

Treatment	Fresh weight g	Lycopene mg/fresh w. 100 g	Carotene mg/fresh w. 100 g	Xanthophyll log T_0/T
10° C (artificial light)				
Control	165	2.5	0.625	0.034
Red cellophane	157	15.0	0.625	0.021
Green cellophane	168	16.88	0.800	0.003
Blue cellophane	199	13.75	0.685	0.017
Black cellophane	183	10.63	0.710	0.012
20° C (artificial light)				
Control	169	14.38	2.50	0.013
Red cellophane	170	19.00	1.25	0.022
Green cellophane	179	10.05	0.80	0.025
Blue cellophane	216	8.75	3.25	0.005
Black cellophane	131	18.75	2.00	0.015
20° C (natural day light + artificial light)				
Control	159	13.75	0.001	0.035
Red cellophane	151	20.65	0.003	0.041
Green cellophane	153	35.00	0.001	0.052
Blue cellophane	180	13.25	0.001	0.018
30° C (natural day light + artificial light)				
Control	176	10.25	1.75	0.018
Red cellophane	154	13.33	2.25	0.037
Green cellophane	197	9.75	1.25	0.013
Blue cellophane	155	11.88	1.88	0.027
Black cellophane	171	19.38	2.75	0.063
25~27° C and 15° C (black)				
25° ~ 27° C	175	13.80	2.75	0.065
15° C	146	14.75	2.95	0.023

the green mature stage and of almost the same fresh weight, this tendency was perhaps due to the fact that the materials were not as uniform as they were considered to be. As for the treatment at different temperature levels, 20° C under natural day light supplemented with artificial light produced more lycopene and xanthophyll in fruits than other storage temperatures. But carotene content was lower than at any other temperatures. It was a general tendency that fruits stored at 20°C and 30°C and exposed to both natural day

Table 22. The content of pigment in tomato fruits covered with colored bags.*

Treatment	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthophyll log T_0/T
Control	23.45	4.50	0.045
Red cellophane	18.25	1.50	0.036
Green cellophane	16.88	1.25	0.010
Blue cellophane	13.55	1.40	0.027
Transparent cellophane	12.25	0.50	0.046

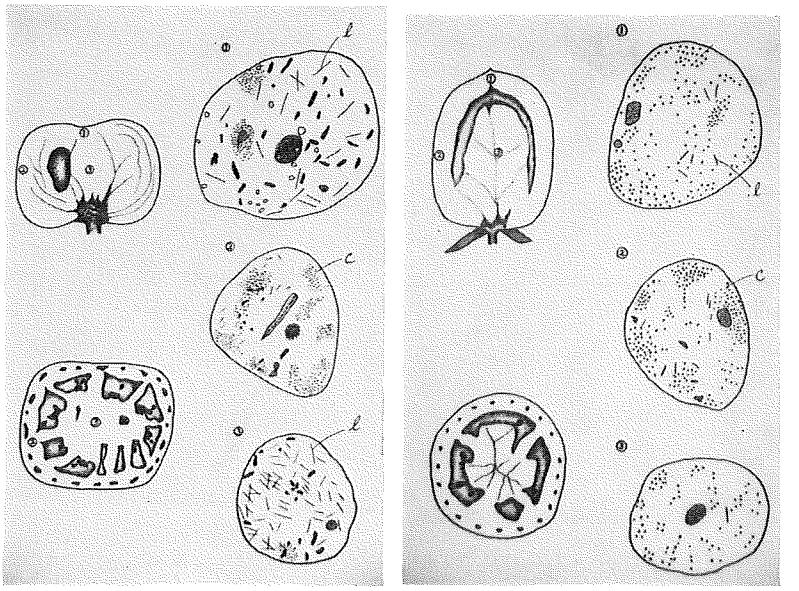
* bagged on Aug. 11 and harvested on Aug. 21.

light and artificial light showed higher pigment contents than fruits exposed to artificial light alone. Green mature fruits of Aichi-tomato were bagged with colored cellophane on August 1, and harvested on August 21. The results of pigment content analysis are shown in Table 22. Non-bagged fruits of control were the highest in each pigment level followed by fruits covered with red, green, blue and transparent cellophane bags in the order.

Fruits of Aichi-tomato and Jubilee were harvested on September 12, and the result of observation on chlomoplast in flesh cells is shown in Figure 18. The chlomoplast in the flower-end, outer part and core in the fruit differed in shape. In Aichi-tomato, needle-shaped pink crystals and short rod-like crystals of lycopene sparsely existed in flesh cells in the flower-end, and yellow granular masses also existed. In flesh cells in the outer part of the exposed side, a few needle-shaped pink crystals and short rod-like crystals of lycopene were present, and the length of these crystals was shorter than that in cells of the flower-end. But yellow granular masses existed in a large number. In the core, needle-shaped pink crystals and short rod-like crystals were contained abundantly, but yellow granular masses were scarce. In fruits of Jubilee, yellow granular masses were seen in the flower-end, outer part and core cells, but needle-shaped pink crystals were scarce. Yellow granular masses were more in the flower-end and outer part cells than in the core cells. Immature fruits of Aichi-tomato and Jubilee were harvested 25 days after flowering, and the result of observation on chlomoplast in cells on the flower-end part of these fruits is shown in Figure 19. Chlomoplasts were mainly chloroplasts, other chlomoplasts being very few.

(2) Result at Shinshu University

Second flower clusters were bagged with vinyl bags of various colors, and light intensity in various bags was measured by a photoelectric meter. Figure



(a) (b)

l : lycopene c : carotene

Fig. 18. The observation of chlomoplast in tomato cells.
(a) Aichi-tomato (b) Jubilee

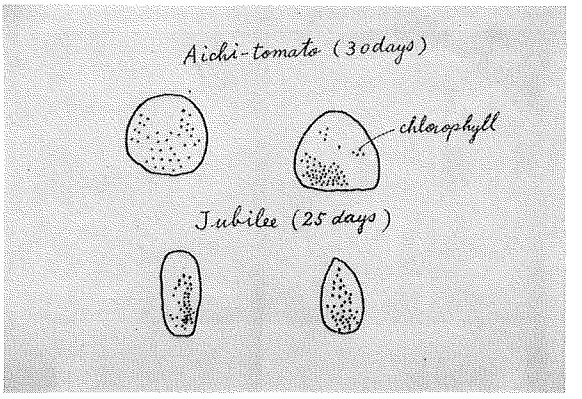


Fig. 19. The observation of chlomoplast in tomato cells.

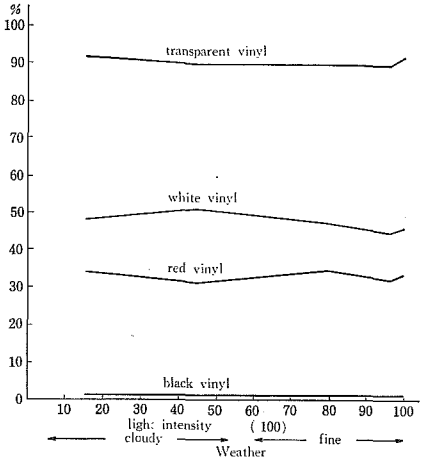


Fig. 20. Degree of decreasing of light intensity in vinyl bags.

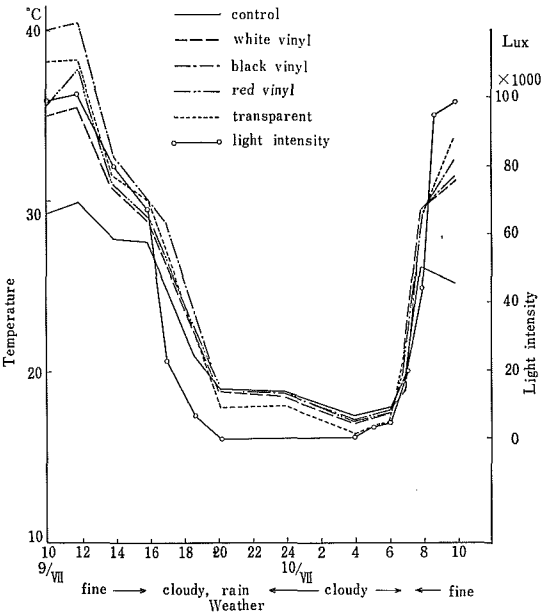


Fig. 21. Daily changes of temperature and light intensity in various bags.

20 shows the light intensities as expressed in per cent of light intensity of natural condition. Light intensity in the vinyl bags was low as compared with the control light intensity. Namely, in transparent, white, red and black vinyl bags it was about 90, 50, 30–35 and 0 per cent respectively. But after the experiment started, water condensed on the inside of vinyl bags, then light intensity in bags was reduced to about 80 per cent of that previously measured.

Daily changes of temperature and light intensity in various bags on July 9 and 10 are shown in Figure 21. The temperature in bags was affected by natural light intensity, and when the light intensity was 7,000 Lux or over the temperature in black bags was the highest, and followed by those in transparent, red and white bags in the order. The temperature of the control lot was always lower than those of the treated lots. In each lot, temperature began decreasing at noon on July 9, and at 4 a.m. on July 10. There were no differences among the night temperatures in treated lots. Average temperature and natural light intensity during 5 days are shown in Table 23. Natural light intensity decreased in middle and late July and middle August, and temperature in various bags decreased correspondingly in these periods. In the case of low temperature period, difference in temperature was slight, while in the case of high temperature period, the difference was large. During the period of measurement, temperature was the highest in the black bag, and was the lowest in the control lot. Temperatures in transparent, red and white

Table 23. Mean temperature and light intensity in various bags during 5 days.

	Transparent vinyl	Red vinyl	White vinyl	Black vinyl	Control	Light intensity
July 5~10	33.6°C	32.4°C	30.6°C	35.6°C	26.0°C	80800Lux
11~15	32.7	33.3	32.5	35.8	24.9	96100
16~20	31.9	33.0	31.6	34.2	28.8	70800
21~25	22.6	22.7	22.4	23.0	21.3	26000
26~31	26.7	26.0	26.1	26.7	22.3	37500
Aug. 1~ 5	35.5	34.1	36.5	35.2	31.9	95500
6~10	32.4	31.2	32.4	32.1	28.2	87000
11~15	27.7	27.8	29.0	28.5	26.0	66000
16~20	27.3	26.7	27.9	27.0	25.9	51000

Table 24. Date of flowering, fruit set and maturity in various bags. (2nd flower cluster)

	Control	Black vinyl	Red vinyl	White vinyl	Transparent vinyl
Flowering date	June 19.4	June 19.7	June 20.9	June 20.7	June 21.3
Setting date of lst fruit	June 28.1	June 29.1	June 28.6	June 28.8	June 29.1
Maturing date of lst fruit	Aug. 14.5	Aug. 17.0	Aug. 14.1	Aug. 13.9	Aug. 13.5
Fruit setting to maturity	47.5 days	48.9	46.2	46.1	45.4
Flowering date	June 22.7	June 21.2	June 20.3	June 23.4	June 22.7
Setting date of 2nd fruit	July 1.6	July 0.8	June 29.5	July 0.2	July 0.6
Maturing date of 2nd fruit	Aug. 15.8	Aug. 18.4	Aug. 15.2	Aug. 14.8	Aug. 14.1
Fruit setting to maturity	45.2 days	48.6	46.7	45.6	44.5
Flowering date	June 24.8	June 24.2	June 24.1	June 24.1	June 23.4
Setting date of 3rd fruit	July 3.0	July 2.1	July 1.7	July 1.7	July 2.6
Maturing date of 3rd fruit	Aug. 17.8	Aug. 19.3	Aug. 17.5	Aug. 17.6	Aug. 15.5
Fruit setting to maturity	45.8 days	48.2	47.5	46.9	43.9

Table 25. Quality of fruits covered with various bags. (60 days after flowering)

Treatment	Dry matter precent %	Viscosity second	Acidity %	pH	Fresh weight g	Sugars %		
						Total sugar	Reducing sugar	Non-reducing sugar
Control	5.48	11.5	0.301	4.4	320	30.44	29.22	1.22
Black vinyl	5.01	10.4	0.410	4.1~4.0	178	32.30	31.06	1.24
Red vinyl	5.04	11.0	0.397	4.1	292	32.30	28.62	3.68
White vinyl	5.19	10.5	0.512	4.0	310	40.20	38.91	1.29
Transparent vinyl	5.01	10.7	0.416	4.1~4.0	228	34.45	33.21	1.24

vinyl bags were not so markedly different.

Dates of setting and maturing of fruits in various vinyl bags are shown in Table 24. The term from fruit setting to maturing was shorter in transparent vinyl bags for the 1st, the 2nd and the 3rd fruits. It was longer for fruits in the black vinyl lot than in any other lots. Among red, white and control lots, the difference was little. Some chemical qualities in fruits covered with various vinyl bags are shown in Table 25. As for dry matter per cent and viscosity, the higher the dry matter coefficient, the larger the viscosity. An inverse relationship is seen between pH and acidity of fruit juice. Vinyl bagged fruits were higher in acidity as compared with control. Accordingly, pH values of juice in bagged fruits were lower than those in control fruits. On the fruits weight, control fruits were the heaviest, and the black vinyl lot produced the lightest of all. On the sugar contents of fruits, the amount of total sugar was larger in vinyl bagged lots than control lot. Especially, fruits in white vinyl bags showed the highest sugar contents of all. Fruits were bagged with various vinyl films 35 days after flowering, then, were harvested 20 days later. Some chemical qualities of these fruits are shown in Table 26. Fruits covered with red and black vinyl bags were damaged. This damage was probably due to high temperature in bags. The viscosity of fruit juice was the highest in fruits bagged with white vinyl film, while little difference in the viscosity was observed among other lots. The acidity of control fruits was higher, and pH was lower, than those in bagged fruits. This relationship was reversed in fruits 60 days after flowering, probably due to the difference in bagging time.

Fruits harvested 35 days and 60 days after flowering, which were bagged after flowering, and fruits bagged 35 days and harvested 55 days after flowering, and fruits bagged with black vinyl film and stored at 21°–25°C after harvest were analyzed for pigment contents. The results are shown in Table 27. Fruits 35 days after flowering did not show sign of lycopene formation. Other pigments, especially chlorophyll, were formed in abundance

Table 26. Quality of fruits covered with various bags.
(55 days after flowering*)

Treatment	Damaged fruits	Viscosity second	Acidity %	pH
Control	0/5	10.4	0.375	4.0~3.95
Black vinyl	3/5	10.4	0.307	4.15
Red vinyl	1/5	10.6	0.264	4.3
White vinyl	0/5	11.0	0.274	4.3

* The fruits were covered with bags for 20 days, starting at 35 days after flowering.

Table 27. Differences in pigment contents among bagged fruits.

Treatment	Chlorophyll mg/fresh w. 100 g	Carotene mg/fresh w. 100 g	Lycopene mg/fresh w. 100 g	Xanthophyll log T_0/T
35 days after flowering				
Control	9.875	0.443	0	0.041
Black vinyl	0.750	0.222	0	0.005
Red vinyl	6.562	0.403	0	0.039
White vinyl	10.750	0.443	0	0.041
Transparent vinyl	8.250	0.363	0	0.035
60 days after flowering				
Control	0	1.128	48.75	0.133
Black vinyl	0	0.363	35.00	0 059
Red vinyl	0	1.058	49.00	0.124
White vinyl	0	1.400	59.50	0.139
Transparent vinyl	0	1.179	44.95	0.136
55 days after flowering (covered for 20 days)				
Control	0	1.461	37.00	0.123
Black vinyl	0	1.139	21.60	0.074
Red vinyl	0	1.118	37.50	0.085
White vinyl	0	1.612	40.75	0.140
21°~25° C storage				
Black vinyl	0	0.635	33.50	0.057

in fruits bagged with white vinyl film. Fruits bagged with black vinyl film were half or less in each pigment content than fruits of other lots, chlorophyll content being especially low. Accordingly, the fruits appeared nearly white. In fruits 60 days after flowering, chlorophyll disappeared, and lycopene appeared in each of bagged fruits. The pigment contents in each bagged fruit were as high as in the fruits 35 days after flowering. Fruits bagged with white vinyl film were high in each pigment content, especially lycopene content. Pigment contents in fruits bagged with black vinyl film were lower than those in fruits bagged with other colors. Pigment contents of fruits harvested 55 days after flowering were the highest among fruits bagged with white vinyl film, and fruits bagged in black vinyl showed the least content than those treated with other colors. The fruits stored at 21°–25°C increased in carotene and xanthophyll contents, as compared with the fruits 35 days after flowering, and formed lycopene. Compared with the fruits bagged with black vinyl film 60 days after flowering, their carotene was twice as much,

and xanthophyll and lycopene contents were nearly the same.

3. Discussion

Pigment contents of fruits bagged with cellophane and vinyl were measured. Cellophane and vinyl bags used were different in the light intensity within. Two experiments were carried out at different locations.

As seen in Table 21, the pigment contents of fruits covered with cellophane bags were controlled by storage temperature, and no consistent difference due to colors of cellopane was observed. But in the fruits stored at 20°C, the pigment contents of those exposed to natural day light supplemented with artificial light were higher than those exposed to artificial light alone. Namely, light intensity influenced formation of pigments, the influence of natural day light being especially stronger. The pigment contents of fruits covered with cellophane film of different colors showed no consistent tendency. That plants used were affected by disease during the experiment and harvested fruits were uniform may have been the reason. Or it is possible that red, green, blue and black cellophane bags used did not affect formation of lycopene so much. In fruits bagged with cellophane while growing on the vine, pigment contents were low as compared with control fruits as shown in Table 22. That temperature in bag was high for formation of each pigment, may be the reason for this difference. Went et al[27] reported that in the fruit maturing at 33°C formation of lycopene was prevented, but production of carotene was normal. For the fruit bagged with cellophane it was also estimated that lycopene content decreased due to high fruit temperature. The influence of temperature was apparent from the observation of chlomoplasts in cells in different parts of the fruits. In the outer part of the fruit usually exposed to light and high in temperature, needle-shaped pink crystals of lycopene were few and yellow granular masses of carotene were abundant. On the contrary, needle-shaped pink crystals were abundant and yellow granular masses were few in the flower-end and core of the fruit. In view of the role of light in pigment formation, as previously reported, carotene and xanthophyll needed the light for their formation. But formation of lycopene did not require light so much. This was estimated from the fact that needle-shaped pink crystals of lycopene were present more abanduntly in the core than in other parts of the fruit.

No clear relationship was detected between light and temperature in vinyl bags. Fluctuations of light intensity did not coincide with temperature in bags. The temperature would be changed, as black vinyl bags absorb heat, transpa-

rent vinyl bags transmit light and white and red vinyl bags have both actions. The fruits covered with transparent vinyl bags showed the highest degree of maturity during the shortest period after flowering, followed by those in white and red vinyl bags, and the longest in black vinyl bags. This order was quite in agreement with the degree of light intensity in bags. It was estimated therefore that maturing of fruit is a function of light intensity. However, in spite of the strongest light intensity given, the term needed for maturing of control fruits was longer than that of fruits in transparent vinyl bags. It was considered that the maturing term of fruit was not only a function of light intensity, but is dependent on temperature, for as shown in Figure 21, the temperature in bags during the day was increased by bagging, sometimes higher by 6°C than control temperature. As for the relationship of bagging and pigment contents of fruits, carotene and lycopene were less in fruits in black vinyl bags, and were most abundant in fruits in white vinyl bags. Xanthophyll content was lower in black vinyl bags, and was almost the same in lots treated with other colors. Then, if the pigment contents in fruits covered with black vinyl bags are compared with those in control fruits, carotene is 31%, xanthophyll 46%, and lycopene 71% of those of control fruit respectively. As seen in Table 27, this shows that appearance of pigments was markedly prevented by shading the fruit. Formation of carotene was prevented most strikingly, while lycopene formation was least affected, by light. Table 28 shows a comparison of pigment contents between fruits bagged with black vinyl film and those bagged with vinyl film of other colors. It is seen from this table that influence of light is strong on carotene formation, and is weak on lycopene formation. Smith[25] and McCollum[12] reported their similar observation. The relationship of pigment contents and light intensity is shown in Figure 22. The result shows that the same amount of pigment is produced even under the light intensity of nearly 30 per cent of the natural light. Nettles et al[18] and Hall et al[6] pointed out that green mature fruits exposed to 10 to 450 F.C. of constant illumination from cool-white fluo-

Table 28. Degree of increasing of pigment contents in fruits in the various bags. (60 days after flowering)

Treatment	Carotone	Lycopene	Xanthophyll	Light intensity
Control	311.1	139	224.5	100
Black vinyl	100	100	100	0.1
Red vinyl	291.6	140.0	210.2	26.40
White vinyl	386.1	170.0	235.6	38.40
Transparent vinyl	325	128.4	230.5	72.80

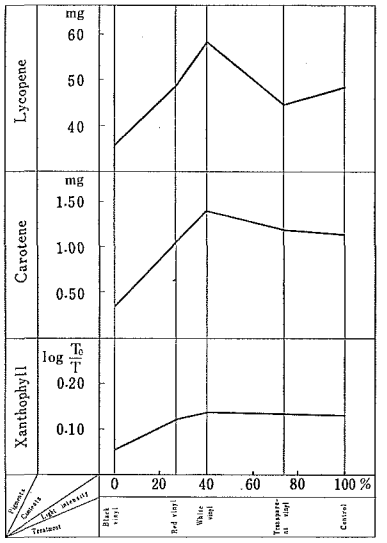


Fig. 22. The relationship between light intensity and pigment contents of fruits in the various bags. (60 days after flowering)

rescent light had significantly higher color values and more total carotenoide than similar fruits ripened in the dark. Accordingly, light intensity producing the pigment need not be as strong as the natural light intensity. Pigment contents of fruits covered with white vinyl bags were higher than those in control fruits, indicating the formation of pigment is better under a limited natural day light than when exposed to the natural day light. But since kinds of light and energies were different for bagged fruits, the question can not be discussed in terms of light intensity alone. Temperature in bags also differed. Therefore in order to examine the effect of bagging on formation of pigments, their interaction will also have to be considered. In the fruits harvested 35 days after flowering, lycopene was not yet formed in those bagged with vinyl of various colors. Fruits bagged with black vinyl film was less in chlorophyll, carotene and xanthopyll contents than those bagged with vinyl films of other colors, chlorophyll and xanthophyll contents being especially lower. The influence of shade was thus indicated to appear from immature stage. The fruits developed in white vinyl bags were the highest in all pigment contents, especially chlorophyll content. It is interesting to note that the comparison of pigment contents showed the same tendency as in fruit 60 days after flowering. The pigment contents in fruits bagged 35 days and harvested 55 days after flowering showed the same tendency as the fruits 60 days after flowering. But carotene and xanthophyll were higher in content in fruits bagged with black vinyl film than in the fruits 60 days after flowering. It was assumed that pigment contents had been influenced by day light before bagging. The fruits 35 days after flowering were harvested and stored at 22°–25°C with black vinyl removed. The pigment contents in the fruits were higher than at the time of harvest, and as compared with the fruits 60 days after flowering, bagged with black vinyl, lycopene and xanthophyll contents were nearly the same, and carotene was twice as much. Also in the fruits grown in black vinyl bag, it was shown that pigments were for-

med while in storage. Especially, to increase the carotene content in fruits, it would be reasonable to expose fruits to light while in storage.

In the fruits at 60 days after flowering, dry matter coefficient and pH value were higher in control fruits, and so the fruit weight was heavier, than that in bagged lots. That normal growth of fruit was prevented by bagging may be the reason for this result. In bagged lots, many cracked fruits and sunburnt fruits developed in transparent vinyl bags, and heavy depauperateness and necrosis of tissue developed in fruits of black vinyl lot. These fruits were probably damaged by high temperature caused by bagging. But as the fruits coverd with white vinyl bags were not damaged, differences among bagging materials were observed.

SECTION 3. THE INFLUENCE OF NUTRITION ON THE PIGMENT CONTENTS AND FRUITS YIELD

Many studies have been made on nutrition of tomatoes. These studies were mainly conducted on nutritional absorption in plant and its effect on fruit yield, while those aimed at examining its effect on fruit quality are scarce. The present experiment were carried out to ascertain the influence of nutrition on the growth of tomato plant, and yield, quality and pigment contents of fruit.

1. Materials and Methods

The experiments were carried out at the Agricultural Eaculty, Shinshu University in 1958 and 1960.

1. In 1958, the experiment was conducted by sand culture. The gravels used were of granite origin, and the variety used was Aichi-tomato. Seeds were sown in hot bed, and transplanted in pot on June 21. Till the third fruit in the first flower cluster was set, the plant was given every day 1/2 liter per pot of standard nutrient solution, as shown in Table 29. After the setting of the third fruit, the nutrient solution (−N, −P, −K, −Mg, O and standard) was given 1 liter per pot every day as shown in the Table. Records were taken on plant growth, number of leaves and fruits, period required for maturing, fruit yield, chemical quality, inorganic matter contents and pigment contents in fruits.

2. In 1960, the experiment was conducted in the field of volcanic-ash soil. The variety used was Sekai-Ichi. Seeds were sown in hot bed on March 27, and transplanted to field on May 23. The fertilizer applied is shown in Table 30. Treatments were the same as in 1958. Records were taken on plant height, the number of leaves, leaf length, the number and yield of fruits, chemical

Table 29. Composition of nutrient solution.

−N	$Ca(H_2PO_4)_2$	: 0.1 g	−P	$Ca(NO_3)\cdot 4H_2O$	: 0.4 g	−K	$Ca(NO_3)_2\cdot 4H_2O$	: 0.3 g
	KCl	: 0.15 g		KNO_3	: 0.21 g		$Ca(H_2PO_4)_2$	: 0.1 g
	$CaSO_4$	: 0.29 g		$NaNO_3$	: 0.16 g		$NaNO_3$	: 0.4 g
	$MgSO_4\cdot 7H_2O$	: 0.26 g		$MgSO_4\cdot 7H_2O$	: 0.26 g		$MgSO_4\cdot 7H_2O$	: 0.26 g
	water	: 1ℓ		water	: 1ℓ		water	: 1ℓ
−Mg	$Ca(NO_3)_2\cdot 4H_2O$	: 0.42 g	O	water	: 1ℓ	Standard	$Ca(NO_3)_2\cdot 4H_2O$	: 0.675 g
	KH_2PO_4	: 0.1 g					KH_2PO_4	: 0.1 g
	KNO_3	: 0.14 g					KNO_3	: 0.14 g
	$NaNO_3$	: 0.18 g					$MgSO_4\cdot 7H_2O$	: 0.26g
	water	: 1ℓ					water	: 1ℓ

Table 30. Amount of fertilzer used. (per plant)

	Ammonium sulfate	Super-phosphate	Potassium chloride	Magnesium sulfate
−N	—	62.5	17.3	42.2
−P	54.9	—	17.3	42.2
−K	54.9	62.5	—	42.2
−Mg	54.9	62.5	17.3	—
Standard	54.9	62.5	17.3	42.2
0	—	—	—	—

quality, inorganic matter contents, and pigment contents in fruits.

In 1958 and 1960, sugars were analyzed following the Bertrand method, and expressed in dry matter per cent. Viscosity was measured with the Ostward viscosity meter at 20°C, and expressed in second. Total acidity was expressed in equivalence of citric acid. On the inorganic matter content of fruit, nitrogen, phosphorus, potassium, calcium and magnesium were analyzed and expressed in dry matter per cent. Pigments were analyzed with the previous method (Chapter 1), and expressed in mg per fresh weigt 100 g for lycopene and carotene, and xanthophyll was expressed in extinction coefficient log T_0/T.

2. Results

1. The result in 1958.

Till the end of the experiment on September 20, normal growth of plants was observed only in the standard lot, leaves in no fertilizer and −N lots were yellowish, and plants in −Mg lot showed a symptom of magnesium deficiency. Plant height and the number of leaves in each lot are shown in Figures 23 and

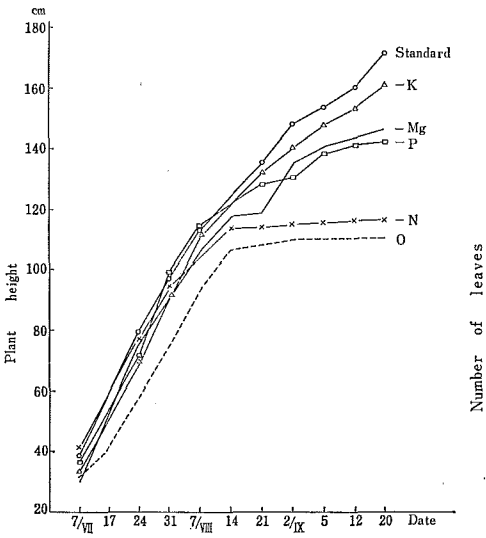


Fig. 23. Height of plant in each lot.

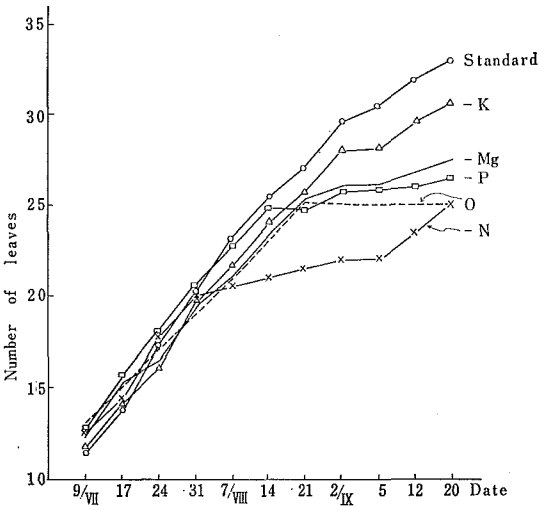


Fig. 24. Number of leaves in each lot.

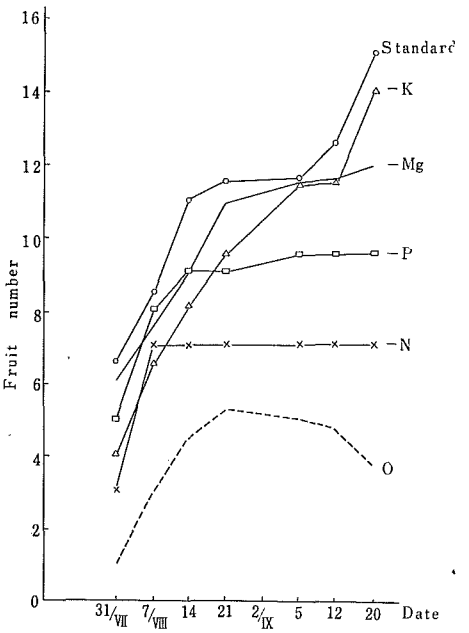


Fig. 25. Number of fruits in each lot.

24. Plant growth in −N and no fertilizer lots stopped in early August, resulting in a low plant height. Growth in the late period in −K, −Mg and −P lots was restricted. Also, increase in the number of leaves as well as in plant height was largest in the standard lot, while smaller in no fertilizer and −N lots. The number of fruits set is shown in Figure 25. Standard lot was the

Table 31. Number of days from fruit set to maturation.

	Fruit set ~ coloring days	Fruit set ~ maturation days	Coloring ~ maturation days
−N	32.0	35.5	3.5
−P	41.1	46.0	4.9
−K	38.2	41.6	3.4
−Mg	41.6	42.2	3.6
0	39.0	45.0	6.0
Standard	42.6	47.7	5.2

Table 32. Fruit yield in each lot.

	Total number of fruits	Total fruit weight g	Mature fruits till Sep. 20th			Immature fruits till Sep. 20th		Percentage of mature fruit %
			Number of fruits	Weight g	Average fruit weight g	Number of fruits	Weight g	
−N	7	1219	5	1005	201.0	2	214	71.4
−P	9.5	1921	6.5	1309	201.4	3	612	68.4
−K	14	2894	4.5	1166	259.1	9.5	1728	32.8
−Mg	12	2656	7	1507	215.6	5	1149	58.3
0	3.7	483	1.5	333	222.0	2.2	150	40.0
Standard	15	3464	6.5	1814	279.2	8.5	1650	43.3

Table 33. Chemical quality of tomato fruit in each lot.

	Dry matter percent %	Viscosity second	Acidity %	pH	Sugars (dry weight %)		
					Total sugars	Reducing sugars	Non-reducing sugars
−N	7.61	14.7	0.432	4.0	47.3	43.0	4.3
−P	7.13	11.9	0.624	4.0	25.8	24.6	1.2
−K	6.34	12.3	0.432	4.1	32.1	30.5	1.6
−Mg	5.59	12.4	0.448	4.18	28.1	27.9	0.2
0	—	—	—	—	—	—	—
Standard	5.56	12.8	0.304	4.2	37.7	35.3	2.4

highest in the number of fruits, followed by −K and −Mg lots. No fertilizer lot suffered from a heavy fruit drop, and the number of fruits was the smallest. The periods from fruit setting to coloring and to maturing are shown in Table 31. The number of days from fruit setting to coloring was shorter in −N lot, and longer in −Mg and standard lots. Harvested fruits and their weight in each lot are shown in Table 32. Total number of fruits was largest in the standard lot, and smallest in the no fertilizer lot. Accordingly, total fruit weight as well as the number of fruits was largest in the standard lot (3463 g per plant), and smallest in no fertilizer lot (486 g per plant).

Table 34. Mineral contents in fruits in each lot. (dry matter %)

	N	P	K	Ca	Mg
−N	1.375	0.445	2.60	0.13	0.104
−P	2.493	0.289	4.30	0.125	0.172
−K	2.191	0.449	2.35	0.15	0.169
−Mg	2.329	0.505	3.85	0.18	0.143
0	—	—	—	—	—
Standard	1.962	0.491	3.65	0.175	0.156

Table 35. Pigment contents in fruit in each lot.

	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthophyll log T_0/T
−N	56.0	1.814	0.143
−P	32.6	1.058	0.093
−K	30.4	1.965	0.123
−Mg	43.0	1.179	0.113
0	—	—	—
Standard	45.9	1.864	0.134

Chemical quality measured for each lot is shown in Table 33. Dry matter coefficient was high in −N lot, and also viscosity was higher. Acidity of fruit juice was higher in −P lot, and lower in standard lot, than in other lots. pH value was recognized to be in an inverse relation with acidity. Sugar contents were highest in −N lot (47.3 per cent) and lowest in −P lot (25.8 per cent). Inorganic matter contents of fruit are shown in Table 34. Nitrogen content was lowest in −N lot, and higher in −P, −Mg and −K lots than in standard lot. Phosphorus content was lowest in −P lot, and highest in −Mg lot. Potassium content was lowest in −K lot, and highest in −P lot. Calcium content was high in −Mg and standard lots, and low in −N and −P lots. Magnesium content was high in −P lot, and low in −N and −Mg lots. Generally, it was seen that plants supplied with nutrient solution lacking a certain element resulted in a lower content of the element in their fruits.

The pigment contents in fruits are shown in Table 35. Lycopene content was highest in −N lot, followed by standard and −Mg lots, and lower in −K and −P lots than in other treatment lots. Carotene content was low in −P and −Mg lots, and not significant in other lots. Xanthophyll content as well as carotene content was high in −N and standard lots, and low in −P and −Mg lots.

2. Result in 1960

In 1960, the experiments were conducted in the field of black volcanic-ash soil. As it was considered that nutrient elements contained in the soil prior to nutrient application would influence the tomato, available inorganic components and pH value of the volcanic-ash soil were measured. The result is shown in Table 36. Phosphoric acid was scarce, being 3.1 mg per 100 g dry weight of soil, but total nitrogen was 194.7 mg per 100 g dry weight of soil. Plant height in lots of different nutrient composition is shown in Table 37. Plant height was taller in standard and −Mg lots, but was shorter in no fertilizer and −P lots, being 138.4 cm and 151.9 cm respectively on August 2. As shown in Table 38, the number of leaves as well as plant height was smallest in no fertillizer lot, but plants of −N and −K lots formed many leaves. Length and width of leaves are shown in Table 39. Both length and width were smaller in no fertilizer and −P lots and larger in −Mg, standard and −K lots. It was

Table 36. Available inorganic components of volcanic-ash soil.

Inorganic matters	mg/dry weight 100 g					pH	
	Total-N	P_2O_5	K_2O	CaO	MgO	H_2O	KCL
Value	194.7	3.1	15.3	18.9	5.2	5.39	5.81

Table 37. Height of plant in each lot. (cm)

	3/June	13/June	23/June	5/July	14/July	23/July	2/August
−N	16.0	23.3	40.0	69.5	99.2	131.3	172.0
−P	14.5	23.0	35.7	62.7	87.5	115.6	151.9
−K	15.3	24.9	46.2	91.3	123.4	156.1	183.9
−Mg	17.6	30.0	56.4	101.0	136.8	163.6	187.9
0	15.7	22.5	34.0	57.5	77.7	103.8	138.4
Standard	16.1	23.8	52.2	97.8	131.5	164.3	195.3

Table 38. Number of leaves in each lot.

	3/June	13/June	23/June	5/July	14/July	23/July	2/August
−N	7.6	9.0	12.9	16.3	19.5	22.6	25.5
−P	9.0	10.2	12.5	16.0	18.2	20.5	23.3
−K	8.6	11.2	13.3	17.5	20.9	23.0	25.0
−Mg	8.5	11.1	14.6	18.5	21.5	23.1	24.9
0	8.3	9.4	12.0	15.2	16.7	18.4	20.9
Standard	8.7	11.0	15.6	18.0	21.2	23.6	24.3

Table 39. Length and width of leaves in each lot.

	Length cm	width cm
−N	35.2	34.7
−P	30.8	27.9
−K	44.3	46.0
−Mg	46.2	49.9
0	28.3	26.8
Standard	44.2	45.3

Table 40. Fruits yield in each lot.

	Number of harvested fruits*				Weight g			
	Large	Middle	Small	Total	Large	Middle	Small	Total
−N	3.9	5.3	0.6	9.8	1749	1179	122	3050
−P	3.7	3.4	0.3	7.4	1380	805	42	2227
−K	6.0	4.6	0.4	11.0	2472	1091	42	3605
−Mg	7.5	4.0	1.0	12.5	3005	866	124	3993
0	1.5	4.5	0.3	6.3	596	1035	28	1659
Standard	6.4	5.2	0.4	12.0	2448	1210	40	3738

* large : over 300 g, middle : 150 ～ 300 g, small : below 150 g

Table 41. Chemical quality of tomato fruit in each lot.

	Viscosity* second	pH	Acidity %	Sugars (dry weight percent)		
				Total sugars	Reducing sugars	Non-reducing sugars
−N	14.0	4.0	0.415	32.30	31.71	0.59
−P	14.4	3.8	0.441	29.00	28.42	0.58
−K	11.7	4.0	0.395	27.25	26.59	0.66
−Mg	11.6	4.1	0.369	29.80	29.25	0.55
0	13.2	4.1	0.395	32.45	32.45	0
Standard	13.0	4.0	0.421	31.24	30.53	0.71

* measurement temperature : 20° C

recognized that phosphoric acid deficiency influenced growth of plant. The number of harvested fruits and their weight are shown in Table 40. The number of harvested fruits was large in standard, −Mg and −K lots, and was small in no fertilizer and −P lots. A similar tendency was observed for fruit weight.

From these facts, it is clear that in the experimental field potassium and magnesium were not applied sufficiently to meet the requirement by the plant for growth but they were supplied from the soil. Accordingly, the fruit yield

was as much as in standard lot. On the other hand, nitrogen level of the soil was a little low, and phosphoric acid was severely deficient. Chemical quality of mature fruit is shown in Table 41. Viscosity was generally higher than in fruits in 1958, especially higher in the fruits in −P and −N lots, and lower in −K and −Mg lots. Acidity of fruit juice was higher in −P lot, and was lower in −Mg lot. Sugar contents were lower in −P and −K lots, and higher in −N and no fertilizer lots. Mineral contents in fruits in each lot are shown in Table 42. Nitrogen content in fruits was not significant in each lot, but was slightly less in fruits of −Mg and −N lots. Phosphorus contents were low in −P and no fertilizer lots, while those of all other lots were more than twice as high as the two lots. The pigment contents in fruits of each lot are shown in Table 43. Lycopene content was high in no fertilizer, −N and standard lots, and was lowest in −P lot. Carotene content as well as lycopene content was lowest in −P lot. Xanthophyll content showed no large difference, but it was lower in fruits in −P lot content than that in other lots.

Table 42. Comparison of mineral contents among treatments.
(dry weight %)

	N	P	K	Ca	Mg
−N	1.99	0.377	2.863	0.140	0.111
−P	2.03	0.139	2.388	0.151	0.109
−K	2.17	0.388	2.443	0.135	0.106
−Mg	1.88	0.361	2.750	0.157	0.066
0	2.01	0.141	2.425	0.109	0.089
Standard	2.03	0.380	2.906	0.151	0.102

Table 43. Pigment contents in fruit in each lot.

	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthophyll log T_0/T
−N	63.5	1.37	0.088
−P	52.5	0.95	0.062
−K	58.0	1.01	0.079
−Mg	54.5	1.33	0.072
0	67.5	1.13	0.090
Standard	65.1	1.27	0.081

3. Discussion

The experiments were carried out to ascertain the influence of nutrition on the growth of plant, and on the yield, quality and pigment contents of fruit. Influence of nutritional deficiency was different between field culture

and sand culture, the latter being stronger in effect than the former. This is probably due to the fact that certain nutrient elements were taken up from the soil supplying deficient nutrient elements. As shown in Table 36 black volcanic-ash soil is high in nitrogen content and less in available phosphoric acid content. Accordingly, if a nutrition lacking phosphoric acid had been applied, its influence for tomato plant would not have been severe. In the sand culture, standard nutrient solution was applied till the fruit setting in the first flower cluster and treatments were started after fruit setting. Then, growth of early stage of tomato plant was little influenced by the absence of fertilizer. The effect of nutritional treatment appeared after the middle stage of growth. Differences in plant height and in the number of leaves appeared more clearly in the late stage than in the early stage. Growth in lots lacking a certain nutrient element was less vigorous than in standard lot, and plant height especially in −N lot was severely restiricted. On the other hand, in the field culture deficiency of phosphorus severely limited plant height than did deficiency of nitrogen. This fact may be explained as follows. Nitrogen content of the soil used was high, and plant could utilize it in a large quantity, and available phosphoric acid needed for plant growth was lacking in the soil.

Fruit yield in −Mg and −K lots in the field culture did not differ from that in standard lot either, but the yield in −P lot decreased more than in no fertilizer lot. However, when a nutrient element was deficient in the sand culture, the yield decreased. In cultivating tomato plants in the field, determination of available nutrient elements contained in the soil prior to cultivation is necessary to control nutrition, and to avoid excess or lack of certain nutritional elements.

Fruits grown in lots where certain nutrients were deficient showed low levels of the elements both in the field and sand culture. In the sand culture, phosphorus deficient fruits showed increased levels of potassium, nitrogen and magnesium. But no consistent tendency was recognized in the field culture. As for the chemical quality of mature fruits in the field and sand culture, dry matter coefficient was increased by nitrogen deficiency, accordingly viscosity of fruit juice was large. When nitrogen was not fully applied, fruit development was restricted, and fruit weight was small, and water content of fruit decreased. As sugar contents increased, dry matter coefficient and viscosity of fruit increased. Fruits grown in phosphorus deficient lot were low in sugar content, pH value of fruit juice was small, and acidity was high. Kobayashi et al[7] reported that acidity of grape fruits increased and sugar content decreased when phosphours was applied in a small quantity. Similar results have been reported on the citrus fruit. Potassium and magnesium deficiency tended to decrease sugar content. Accordingly, in order to improve the fruit quality,

phosphorus, potassium and magnesium should be applied sufficiently, and it is important that nitrogen is applied in a small quantity.

The pigment content of fruits was influenced by nutrition, both in the field and sand culture, and the fruits of no fertilizer and −N lots showed good coloring. This is explained by the fact that as shown in Tables 35 and 43 lycopene contents in no fertilizer and −N lots were higher than in the other lots. On the other hand, lycopene contents in −P, −K and −Mg lots were low. These fruits were harvested at the same stage, and fruits of higher pigment contents were more matured than those of lower pigment contents. Accordingly, nitrogen deficiency promoted maturing, and deficiency of phosphorus, potassium or magnesium delayed maturing. Especially, the influence of phosphorus deficiency was the largest. To promote the coloring of fruits it is important to apply phosphorus and to avoid application of excess nitrogen. Carotene and xanthophyll contents in fruits were decreased by phosphours deficiency. These facts indicate that a nutrient element related to coloring of fruits most closely is phosphoric acid.

Nitrogen deficiency, in spite of its restricting effect on plant growth and the yield, increased sugar and pigment contents. However, phosphorus deficiency restricted plant growth, and decreased sugar and pigment contents, and then increased total acidity of fruit. It is considered that in order to obtain fruits of good color, the amount of nitrogen should be as small as possible so far as the yield is not decreased, while phosphorus should be applied sufficiently to avoid its deficiency.

CHAPTER 5
EFFECT OF STORAGE TEMPERATURE ON PIGMENT CONTENTS IN FRUITS

Denisen[2] described that temperature is an important factor for the coloring of tomato fruits. For their coloring while in storage, not only the storage temperature but also maturity of fruit is an important factor. This experiment was designed to ascertain the influence of storage temperature and harvesting time on the chemical quality and pigment contents of fruits.

1. Materials and Methods

The experiments were conducted at the Agricultural Faculty, Shinshu University from 1959 to 1961. The varieties used were Kurihara in 1959 and Mitsuoka in 1960 and 1961. Their cultivation and management were made following the customary method. Fruits used for storage test were taken from the second and upper flower clusters.

In 1959, fruits were harvested 38 days after flowering and stored at 30°,

22° or 15°C. As the control, fruits were left to grow on the vine. The number of days from flowering to coloring, acidity, viscosity and pigment contents of fruits were recorded. In 1960, fruits were harvested 15, 25, 35, 45, or 55 days after flowering, and stored at room temperature (25°C). Chemical quality and pigment contents of these materials were examined. In 1961, fruits were stored 38 days after flowering at 35°, 30°C or room temperature (23°–28°C) respectively for 16 days, and then each group of treated fruits was stored at room temperature for 7 days. Each fruit was measured for chemical quality and pigment contents.

As for the chemical quality, viscosity was measured with Ostward viscosity meter, and expressed in second. Acidity was expressed as citric acid per cent. Sugars were analyzed with Bertrand method and expressed in dry matter per cent. Pigment contents were analyzed with the same method described in the Chapter 1, and the dates are tabulated.

2. Results

The results showing the influence of storage temperature on the number of days from flowering to coloring and on pigment contents are shown in Table 44. The periods from flowering to coloring and to maturing were shorter in fruits stored at 30°C and 22°C than in control fruits. The period was the shortest in fruits stored at 30°C. On the other hand, fruits stored at 15°C needed a longer period than control fruits. Acidity of stored fruits was high, the tendency intensified by higher temperatures. As for the pigment contents, lycopene content was the highest in fruits stored at 22°C. No marked differrence in lycopene content was found between fruits stored at 30°C and control fruits. Fruits stored at 15°C showed the least lycopene content. However, carotene content was high in fruits stored at 15° and 22°C, and the least in control fruits.

Fruits harvested 15, 25, 35, 45 and 55 days after flowering and stored at

Table 44. The effect of storage temperature on the coloring of tomato(1) fruits. (1959)

Storage temperature	No.of days flowering to coloring	No.of days flowering to maturing	Fruit weight g	Acidity %	Viscosity %	Lycopene mg/fresh weight 100 g	Carotene mg/fresh weight 100 g	Xanthophyll $\log T_0/T$
30	45.4	48.4	92.7	0.97	11.0	33.25	1.16	0.128
22	48.6	52.0	99.8	0.58	12.5	43.37	1.29	0.088
15	56.8	61.1	81.5	0.56	11.5	25.25	1.31	0.075
Control(2)	52.0	58.6	206.8	0.35	11.5	35.50	0.97	0.084

(1) harvested at 38 days after flowering
(2) matured on plant

Table 45. Differences in the weight and coloring among fruits harvested at various stages after flowering. (1960)

No. of days after flowering	Fruits weight			No. of days flowering to coloring	No. of days flowering to maturing	Length of storage days
	Before storage g	After storage g	After/Before ×100			
15	20.4	14.6	71.6	39	47	35
25	92.0	82.2	89.3	39	45	22
35	172.4	161.1	93.4	43	49	16
45	251.6	241.8	96.1	46	52	10
55	302.2	—	—	—	—	0

storage tempreature : 25°C

Table 46. Differences in chemical quality among fruits harvested at various stages after flowering. (1960)

Days after flowering	Viscosity second	Acidity %	pH	Reducing sugars %		Total sugars %		Non-reducing sugars %		Starch %	
				Before storage	After storage	Before storage	After storage	Before storage	After storage	Before storage	Before storage
15	—	—	—	20.68	21.79	24.55	22.63	3.87	0.84	18.3	0.3
25	18.6	0.738	3.9	22.89	31.87	24.84	34.00	1.95	2.13	16.0	0.3
35	13.9	0.466	4.05	34.22	30.78	35.67	34.56	1.45	3.78	8.7	0
45	12.7	0.421	4.0	31.36	32.50	34.00	35.11	2.64	2.61	3.4	0.5
55	11.0	0.434	4.0	37.67	—	38.62	—	0.95	—	0.5	0

storage temperature : 25°C

Table 47. Differences in pigment contents among fruits harvested at various stages after flowering. (1960)

Days after flowering	Chlorophyll mg/fresh weight 100 g		Lycopene mg/fresh weight 100 g		Carotene mg/fresh weight 100 g		Xanthophyll log T_0/T	
	Before storage	After storage	Before storage	After storage	Before storage	After storage	Before storage	After storage
15	16.60	0	0	81.50	1.16	1.49	0.101	0.109
25	8.33	0	0	48.00	0.45	1.41	0.069	0.090
35	4.75	0	0	35.75	0.30	1.13	0.049	0.071
45	2.19	0	0.78	51.00	0.78	1.45	0.056	0.093
55	0	—	59.25	—	1.73	—	0.086	—

storage temperature : 25°C

25°C were recorded for fruit weight and the number of days from flowering to coloring. The results are shown in Table 45. Early harvested fruits were light in weight, and decrease of weight during storage was great. The periods from flowering to coloring and maturing were shorter in early harvested fruits. Especially, fruits harvested 15 and 25 days after flowering were colored 39

days after flowering. The pigment contents and chemical quality of these fruits before and after storage are shown in Tables 46 and 47. Fruits harvested from the plant early were higher in viscosity and acidity, and were lower in pH. The sugar contents were not significantly different between fruits before and after storage. But fruits left on the vine required a longer growth term, though they were high in sugar content. On the other hand, starch content of fruits was inversely relative to sugar content. Fruits after storage were lower in starch content than those before storage, and contained starch only at 0–0.5 per cent of the dry matter. Starch content in fruits before storage decreased as harvesting time was delayed. As for the pigment contents in fruits before storage, chlorophyll was found in fruits till 45 days after flowering, and lycopene had not appeared. But in fruits after storage, chlorophyll content was found decreasing at each harvest time, and lycopene appeared and its content was almost the same as in fruits at 55 days after flowering. Especially, fruits harvested 15 days after flowering and stored were high in lycopene content—81 mg per fresh weight 100 g. However this was probably due to a marked decrease of fresh weight resulting from loss of water. Carotene and xanthophyll contents of fruit were high in fruits after storage than in those before storage at each harvest time.

Fruits harvested at 38 days after flowering were stored at 35°, 30°C or room temperature (23°–28°C) for 16 days, and then stored at room temperature (23°–28°C) for 7 days. The chemical quality and pigment contents of these fruits are shown in Tables 48 and 49. Viscosity of fruits stored at 30° and 35°C was higher than those in fruits stored at room temperature. This tendency was not changed even in storage at room temperature for 7 days. Acidity was high in fruits stored at 30°C. Carotene and xanthophyll contents were low in fruits stored at higher temperatures. Even when these fruits were stored at room temperature for 7 days this tendency was not changed. Lycopene did not appear, and chlorophyll disappeared, in fruits stored at 35°C, rendering fruit color yellow. Lycopene appeared in fruits stored at 30°C and those at room temperature. Especially fruits stored at room temperature were high in lycopene content. When these fruits were stored at room temperature for 7 days, lycopene appeared in fruits that had been stored at 35°C for 16 days, its content being 37.47 mg per fresh weight 100 g. Lycopene formation was inhibited in fruits stored at 35°C, but when these fruits were stored at a lower temperature 23°–28°C, lycopene appeared. Accordingly, the mechanism of lycopene formation was not destroyed in fruits during their storage at 35°C.

3. Discussion

The experiments were carried out to ascertain the influence of storage

Table 48. Comparison of chemical quality among the fruits stored at various temperatures. (1961)

(1) Storage temperature C	Viscosity second	pH	Acidity %	(2) Storage temeprature C	Viscosity second	pH	Acidity %
35°	15.9	4.3	0.45		13.9	4.2	0.48
30°	20.6	4.0	0.61	23°~28°	19.6	4.2	0.50
23°~28°	10.6	4.2	0.48		10.7	4.2	0.48

(1) : fruits harvested at 38 days after flowering and stored for 16 days.
(2) : fruits stored for 7 days following the treatment (1).

Table 49. Comparison of pigment contents among the fruits stored at various temperatures. (1961)

(1) Storage temperature C	Carotene mg / fresh weight 100 g	Lycopene mg / fresh weight 100 g	Xanthophyll log To/T	(2) Storage temperature C	Carotene mg / fresh weight 100 g	Lycopene mg / fresh weight 100 g	Xanthophyll log T_0/T
35°	1.055	0	0.054		1.016	37.47	0.086
30°	1.640	24.42	0.084	23°~28°	1.680	42.22	0.097
23°~28°	1.875	28.89	0.093		1.758	43.33	0.107

(1) : fruits harvested at 38 days after flowering, and stored for 16 days.
(2) : fruits stored for 7 days following the treatment (1).

temperature and harvest time on the chemical quality and pigment contents of tomato fruits. If storage temperature was below 30°C, the period from flowering to coloring was shorter at higher and longer at lower temperatures. It was estimated that metabolism of fruit was hastened by high temperature, and the fruit was brought to mature condition faster. On the other hand, low temperature controlled metabolism, delaying coloring of fruits. Lycopene content was highest in the fruit stored at 22°C. On the lycopene formation, Vogele[26] described that 24°C was the optimum temperature, and Duggar[3] pointed out that 18°–23° C was optimum, furthermore Denişen[8] reported that 20°–25°C was the optimum temperature. Thus, temperature is an important factor in lycopene formation. Judging from the results of this experiment and the reports by these workers, it seems that the optimum temperature for storing fruits is 20°–25°C.

When fruits harvested at different stages and stored at 25°C are compared, the period from flowering to coloring was shorter in early harvested fruits. As fruits did not receive the nutrient supply from mother plants after detached those harvested early were small. Therefore such fruits reached the mature condition and attained an early coloring due to the chemical change caused by respiration. But though sugar content of fruits increased as they matured, differences in sugar content between fruits before and after storage were not

great. Starch content decreased with fruit growth and became very small. There was no difference due to harvest time in the starch content of fruits after storage. Accordingly, the degree of matureness of fruit is related with its starch content. The time of lycopene appearance in fruit was about 45 days after flowering, and the starch content at that time was about 3.4 per cent of dry matter, but it decreased to 0.5 per cent in fruits at 55 days after flowering, when the whole fruits were colored and reached maturity.

In fruits stored at 35°C, their color was yellow as lycopene did not appear. It shows that carotene and xanthophyll were produced in the fruits, though smaller in amount as compared with their amounts produced at optimum temperature. And it was observed that disappearance of chlorophyll in fruits stored at 35°C took place later than in fruits stored at room temperature. However, when these fruits were moved to optimum temperature, lycopene was formed rapidly. This fact was interpreted to mean that the mechanism of lycopene formation was not destroyed in fruits stored at 35°C and that lycopene formation was only suspended by high temperature. The same phenomenon was shown by Vogele[26], and Went et al[28] reported that when detached tomatoes are ripened at 33°C, no lycopene is formed although all other pigments develop normally. Then storage at high temperature was not only bad for coloring of fruit, but lowered its chemical quality.

When storing tomatoes, storage temperature is optimal at 20°–25°C for the pigment content and chemical quality of fruit. When temperature is 30°C or above, appearance of lycopence is suppressed, and when temperature is 15°C or below, a longer period is needed for coloring.

CHAPTER 6
RELATIONSHIP BETWEEN RESPIRATION AND COLORING OF FRUITS

Studies have been made to examine the influence of environmental conditions on the coloring of tomato fruits. In spite of these studies, however, it is not clear whether coloring of fruit is directly influenced by environmental conditions, or metabolism of fruit is influenced by environmental conditions, which in turn influences coloring. Therefore, an experiment was carried out to examine the relationship between respiration and coloring of fruit.

1. Materials and Methods

The experiment was conducted in 1960 and 1961 at the Agricultural Faculty, Shinshu University. The variety used was Mitsuoka. In both years cultivation

and management were carried out by the customary method.

1. In 1960, fruits were picked from plants at 10 a.m. 30, 38, 47 and 52 days after flowering, stored at room temperature (26°±2°C), and measured for respiration rate every three days beginning on the day they were picked. Coloring of fruits in storage was observed, and pigment contents and chemical quality of fruits before and after storage were measured.

2. In 1961, fruits were picked from plants 25, 33, 37, 41 and 43 days after flowering, stored at room temperature (22°–25°C), and were measured for respiration rate every other day beginning one day after they were picked. Coloring of fruits in storage was observed, and pigment contents and chemical quality of fruits after storage were measured.

Fruits picked 39 days after flowering were stored at 35°, 30° and room temperature (22°–25°C), and were measured for respiration rate and coloring grade every other day.

Fruits harvested 40 days after flowering were placed in the air containing oxygen (21%) and carbon di-oxide (1%) for 10-day storage from August 26 to September 5, and their coloring was observed. Each stored fruit was analyzed for pigment contents and chemical quality on September 5, when control fruits were growing on the vine.

The measurement of respiration rate was conducted with closed method using 5 liter desiccators, and carbon di-oxide exhausted during 3 hours from 12 a.m. to 3 p.m. was expressed in mg per hour per fresh weight 1kg. Pigment contents were measured and expressed as in the previous experiment. Storage in oxygen or carbon di-oxide was conducted using 12 liter desiccators. Carbon dioxide in the desiccator was removed prior to the experiment, and carbon dioxide evolved from fruits was absorbed by 25 per cent solution of potassium hydroxide during the experiment. In the carbon di-oxide storage, oxygen in the desiccator was removed with pyrogallol alkaline solution beforehand. The gas concentration at the beginning of storage was about 21 per cent for the former, and 1 per cent for the latter.

2. Results

1. The respiration rate of fruits in 1960 is shown in Figure 26. In each fruit harvested, the climacteric peak of respiration rate appeared when the whole fruit was colored, but it appeared earlier in fruits harvested earlier. The respiration rate was the highest on the harvest day in each harvested fruit, which was probably due to abnormal respiration brought about by harvesting. The pigment contents in these fruits at the time of harvest and after the respiration measurement are shown in Table 50. Lycopene, carotene and xanthophyll con-

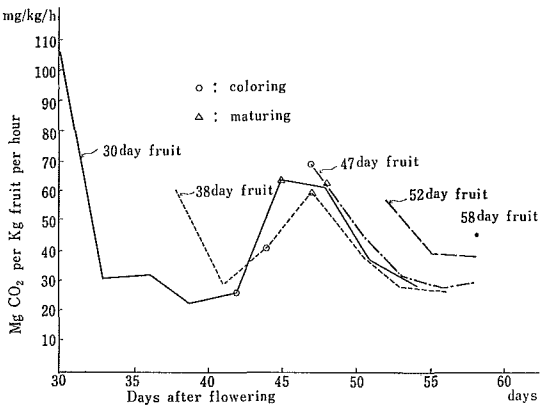


Fig. 26. Respiration rates of tomatoes at different stages of development.

Table 50. Change of pigment contents in tomato fruits.

Days after flowering	Chlorophyll mg/ fresh weight 100 g		Lycopene mg/fresh weight 100 g		Carotene mg/fresh weight 100 g		Xanthophyll log To/T	
	At harvest	After measurement	At harvest	After measurement	At harvest	After measurement	At harvest	After measurement
30	6.00	0	0	43.80	0.33	1.07	0.052	0.075
38	5.13	0	0	37.50	0.55	1.07	0.051	0.063
47	3.19	0	2.55	49.00	1.01	1.27	0.061	0.087
52	0.95	0	25.63	54.00	1.73	1.72	0.068	0.088
58	0	—	69.00	—	1.92	—	0.108	—

Table 51. Changes of chemical qualities in tomato fruits.

Days after flowering	Viscosity second	Acidity %	pH
30	16.8	0.557	3.9
38	12.9	0.466	4.1
47	14.3	0.434	3.9
52	12.8	0.415	4.1
58	10.8	0.421	4.1

tents in fruits were high in fruits harvested later. Fruits 58 days after flowering were highest in pigment contents. Chlorophyll content in fruits showed a reverse trend, and the pigment was little in fruits 58 days after flowering. All fruits harvested on different dates colored on the whole surface at the end of respiration measurement, pigment contents did not differ among fruits of

Table 52. Changes of sugar contents in tomato fruits.

Days after flowering	Reducing sugar %		Total sugar %		Non-reducing sugar %		Stach %	
	At harvest	After measurement	At harvest	After measurement	At harvest	After measurement	At harvest	After measurement
30	24.8	25.2	27.6	27.1	2.8	1.9	15.2	0
38	27.4	27.4	28.2	31.6	0.8	4.2	9.9	0.3
47	31.4	29.1	32.8	32.2	1.4	3.1	2.6	0
52	38.7	34.2	40.1	38.6	1.4	4.4	0.5	0
58	41.2	—	41.6	—	0.4	—	0	—

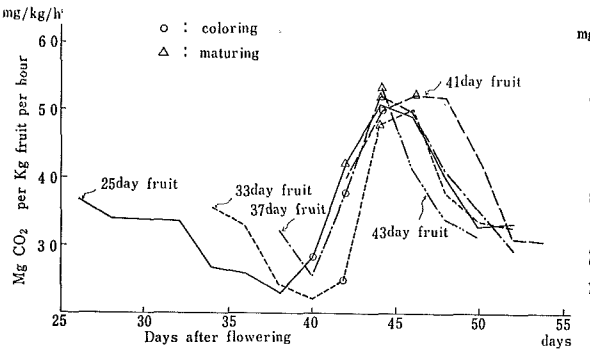


Fig. 27. Respiration rates of tomatoes at different stages of development.

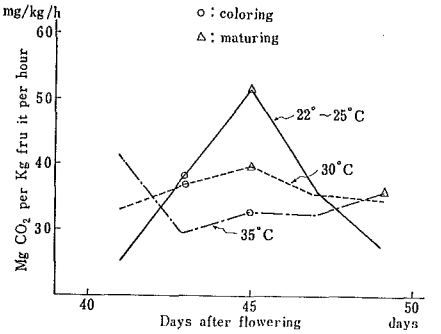


Fig. 28. Respiration rates of tomatoes* in storage of different temperatures.
* 39 days after flowering

Table 53. Changes of pigment contents and qualities in tomato fruits.

Days after flowering	Lycopene mg/fresh weight 100 g	Carotene mg / fresh weight 100 g	Xanthophyll log To/T	Viscosity second	Acidity %	pH
25	39.90	1.451	0.072	19.3	0.46	4.25
33	34.75	1.351	0.067	11.5	0.47	4.15
37	35.00	1.221	0.060	11.7	0.48	4.15
41	33.00	1.351	0.067	12.4	0.46	4.20
43	37.53	1.472	0.073	13.8	0.44	4.10

different harvest days, but the later the fruits were harvested, the more pigment they contained. And chlorophyll disappeared in every fruit tested. The chemical quality in these fruits is shown in Tables 51 and 52. Viscosity and acidity of tomato juice increased in fruits harvested later, and sugar content was low in fruits harvested earlier. But starch content decreased in fruits harvested later, and the fruits after respiration measurement scarcely contained starch at each recording time.

2. The respiration rate of fruits in 1961 is shown in Figure 27. Harvest day in 1961 was earlier than in 1960, and the respiration measurement was started on the next day of harvest. The abnormal respiration mentioned above was not observed. The climacteric peak of respiration rate appeared in entirely colored fruits as in 1960, and the respiration rate decreased thereafter. The period of minimum respiration rate was about 40 days after flowering, corresponding to the mature green stage, followed by the coloring stage of fruits. Accordingly, the respiration rate of fruit decreased from immature to mature stage, and increased from mature green to whole fruit coloring. The climacteric peak was formed, and thereafter respiration rate decreased. The pigment contents and chemical quality of these fruits after respiration measurement are shown in Table 53. Pigment contents in each harvested fruit were not different, but viscosity of fruit juice was large in fruits 25 days after flowering.

The respiration rates as influenced by storage temperature in fruits 39 days after flowering are shown in Figure 28. The climacteric peak of respiration rate in fruits stored at 20°–25°C appeared 45 days after flowering, and their respiration rate was higher than in fruits stored at 30° and 35°C, and a drastic change occurred in respiration rate. The climacteric peak in fruits stored at 35°C was not clear, and the coloring date was 45 days after flowering, then the whole fruits colored 49 days after flowering. But the fruit color was yellow and red pigment was not seen.

Fruits 40 days after flowering were stored for 10 days in a desiccator containing oxygen (about 21%) or carbon di-oxide (about 1%) to control the respiration rate and thereafter their fruits were examined for pigment contents and chemical quality. The results are shown in Table 54. As control, fruits 50 days after flowering were harvested. Fruits stored in oxygen were higher in pigment contents than those stored in carbon di-oxide. Namely, carbon di-oxide storage inhibited maturing of fruits. But the fruits stored in oxygen contained already less pigment than control fruits. When the storage was started, oxygen was about 21 per cent, but oxygen was used by respiration of fruits during their

Table 54. Comparison of pigment contents and chemical qualities among the fruits stored under different air condition.

	Lycopene mg/fresh weight 100 g	Caroteue mg/fresh weight 100g	Xanthophyll $\log T_0/T$	Chlorophyll mg/fresh weight 100g	Viscosity second	Acidity %	pH
O_2	28.13	1.453	0.077	0	12.6	0.478	4.15
CO_2	0.84	0.516	0.026	1.187	18.7	0.582	3.80
Control	30.90	1.725	0.083	0	10.1	0.450	4.20

storage for 10 days, and this decrease in oxygen concentration retarded maturing of the fruits as compared with control fruits. Fruits stored in carbon di-oxide were high both in viscosity and acidity, than those stored in oxygen. After storage for 10 days, the whole fruits stored in carbon di-oxide were still green due to chlorophyll though they were beginning to color.

3. Discussion

The respiration rate of fruits decreased as they grew from immature to mature green stages, became lowest in mature green stage, and increased again as the whole fruit was colored. The rate reached its climacteric peak, followed by redecrease thereafter. In this case, the decrease of respiration rate up to mature green stage agreed with decrease in contents of chlorophyll, carotene and xanthophyll in fruits. The following increase of respiration rate agreed with the appearance of lycopene and the increase in contents of the other carotenoide pigments. Especially, the rapid increase of respiration rate after mature green stage was in parallel with the rapid increase of lycopene. The metabolism in fruits may have rapidly increased due to appearance and formation of lycopene, increasing the respiration rate. After the whole fruit was colored, the respiration rate decreased. In this stage, the fruit was in a over-mature condition, suggesting a decrease in fruit metabolism.

Temperature was one of the environmental factors most influential to the respiration rate of fruits. In general low temperature was found to depress the respiration rate. Platenius[21] reported that respiration rate rapidly decreased when temperature was 10°C or below. In this experiment, though the respiration rate was measured at room temperature or above, difference in respiration rate was large at room temperature, while small at 30° or 35°C. Respiration rate at room temperature temporarily increased, and the climacteric peak appeared, but respiration rate was mostly lower than in fruits stored at 30° or 35°C. On the other hand, respiration rate of fruits stored at 30° and 35°C was generally high, and appearance of the climacteric peak was not clear. In this case, increase of respiration rate was clearly observed in fruits stored at room temperature during the period from lycopene appearance to coloring of the whole fruit, but in fruits stored at 35°C, the term from coloring to coloring of the whole fruit was obscure. Pigments contained in fruits were mainly lycopene at room temperature, while at 35°C they were mainly yellow pigment such as carotene, lycopene being present only in a small quantity as described in the previous chapter. Pigment contents of fruits stored at 30°C were intermediate between those stored at room temperature and 35°C. Accordingly, appearance of the climacteric peak in respiration rate was thought to have some relation

to appearance and production of lycopene.

Among other factors influencing respiration rate are oxygen and carbon di-oxide concentrations in the air. When fruits were stored in oxygen (21%) and carbon di-oxide (1%), maturing of fruits in the latter was later than that in the former, and it was obvious from the examination on pigment contents in this experiment that oxygen supply was necessary in lycopene formation. Storage in carbon di-oxide depressed respiration rate of fruits, and prevented the decrease of storage nutrient in fruits. Accordingly, when fruits are to be stored for a long period, it will be more effective if the oxygen concentration is lower and the carbon di-oxide concentration is higher than those in the air.

CONCLUSION

The experiments were carried out to ascertain how the coloration of tomato fruits is influenced by environmental condition and cultivating method. In addition, researches on growth of plant and quality of fruit were made.

The pigments contained in fruit were lycopene, carotene and xanthophyll of carotenoide pigment, and chlorophyll. Chlorophyll was contained in immature fruit, and disappeared about 43–46 days after flowering. Carotene and xanthophyll were contained both in immature and mature fruits, but their contents in mature fruits were higher than in immature fruits. Lycopene was contained in mature fruits, and appeared in fruits about 38–40 days after flowering.

The carotene and xanthophyll contents were not different among the tomato varieties used, but the lycopene content was higher in F_1 varieties than in others.

As for the relationship between environmental factors and pigment contents in fruits, the carotene and xanthophyll contents were increased by exposure to light, while lycopene was controlled not by light but by temperature. The optimum temperature for lycopene formation was 20°–25°C. Lycopene was formed in dark condition. Fruits showed differences in the pigment content when bagged with vinyl film of various colors, but not when bagged with cellophane of various colors. In fruits bagged with white vinyl lycopene content was higher than in those covered with vinyl bags of other colors and control. The deficiency of nutrient elements affected the pigment content in fruits. Fruits developed on the nitrogen deficient plant were the highest in lycopene content, while fruits developed on the phosphorus deficient plant were the least in lycopene content.

Fruits stored at room temperature (20°–25°C) had the highest content in lycopene. When storage temperature was 35°C or above lycopene did not appear in fruits, and their color was yellow. However, storage temperature of 15°C or

below depressed appearance of lycopene, carotene and xanthophyll. The coloration was earlier in fruits stored at 20°–30°C than in those developed on the vine.

Respiration rate of fruit was high when the whole fruit was colored. Though fruits stored at high temperature was high in respiration rate, but formation of the climacteric peak was not clear. Storage in CO_2 (about 1%) inhibited respiration, and oxygen (about 21%) accelerated respiration of fruits.

In order to attain a good coloring of tomato fruits, the fruit developing on the vine should be shaded with leaves, and direct sun light should be avoided. Temperature throughout the cultivating season needs to be 20°–25°C. Nutrition should be less in nitrogen, and more in phosphorus. In the case of storing fruits, storage temperature should be controlled to 20°–25°C.

For the long storage, the concentration of carbon di-oxide must be maintained about 1 per cent or slightly more, and the temperature lower than 20°–25°C optimum temperature.

SUMMARY

This study was carried out from 1957 to 1961 to thoroughly investigate how the coloration of tomato fruits is influenced by environmental condition and cultivating method, using 28 varieties at the Agricultural Faculty, Shinshu University. In addition, reserches on growth of plant and quality of fruits were made.

1. In analyzing pigments, the column chromatographic method was used, in which calcium carbonate and active aluminium oxide were used as adsorbents, and aceton, petroleum benzine and ethyl ether as solvents.

2. In determining the concentrations of pigments in the extracts, the extinction coefficients were measured for chlorophyll, xanthophyll, carotene and lycopene with wave length 660, 440, 448 and 470 mμ respectively, using the 1 cm cell of BECKMANN DU spectrophotometer. The concentration of each pigment was estimated from the extinction coefficient obtained by means of the standard calibrated curve.

3. Chlorophyll, carotene and xanthophyll were detected in young fruits already five days after flowering, but these pigments decreased with the fruit growth. About 45 days after flowering, chlorophyll could no longer be detected. On the other hand, carotene and xanthophyll increased as chlorophyll disappeared and fruits matured. Lycopene was not present in fruits until 40 days after flowering, but appeared at the time of disappearance of chlorophyll and increased rapidly thereafter. Chlorophyll content was high in younger fruits, and carotene, lycopene and xanthophyll contents were high in mature fruits.

4. Among the 28 varieties, it was observed that the number of flowers increased in flower clusters of higher positions, but the setting rate of their fruits decreased. Accordingly, the coefficient of fruit set decreased in higher flower clusters. Varieties Shugyoku, Ponderosa and Aichi-tomato had more flowers than the others. Variety Shugyoku showed the highest fruit setting among the varieties observed, and its coefficient of fruit set for the first three flower clusters was 97.5 per cent.

5. Lycopene content was higher in Kikyoiku-Ichigo, Kiyosu-Nigo, and Furuyawase in 1958 and in Oogata-Akafuku and Oogata-Fukuju in 1959 than in the other varieties. Lycopene contents of varieties in 1959 were higher than those in 1958, while there were no difference in carotene and xanthophyll contents between the fruits produced in both years.

6. Chlorophyll, carotene and xanthophyll contents in exposed fruits were much higher than in shaded ones. Lycopene content from 40 days to 55 days after flowering was slightly higher in exposed fruits than in shaded ones, but

that in fruits 60 days after flowering was much higher in shaded fruits than in exposed ones.

7. Young and mature exposed fruits were cut into upper and lower halves. Chlorophyll, carotene, xanthophyll and sugar contents in young fruits, and carotene and xanthophyll contents in mature fruits were much higher in the lower half than in the upper half, but in mature fruits, lycopene and sugar contents of the upper half were higher than in the lower half.

8. Immature and mature exposed fruits were divided into exposed and shaded sides. Chlorophyll, carotene and xanthophyll contents of immature fruits, and carotene and xanthophyll contents of mature fruits were much higher in the exposed side than in the shaded side, but lycopene content in mature fruits was higher in the shaded side than in the exposed side.

9. Microscopical observation on chlomoplasts revealed many yellow granular masses in the flesh of the outer part of the fruits and needle-shaped pink crystals of lycopene in the flesh cells of the flower-end and the core of the fruit. Especially, flesh of the core had the largest amount of lycopene.

10. Fruits covered with white vinyl bag had the largest amounts of chlorophyll, carotene, lycopene and xanthophyll among fruits covered with vinyl bags of various colors. Fruits covered with black vinyl bag had the smallest amount.

11. As for pigment contents, phosphorus deficient fruits contained less lycopene, carotene and xanthophyll, but nitrogen deficient fruits contained more lycopene than control fruits.

12. Fruits stored at 22°C contained more, and those stored at 15°C contained less, lycopene than those stored at other temperatures.

13. Lycopene content in fruits stored at 35°C was small, but fruits subsequently stored at room temperature produced lycopene.

14. The respiration rate of fruits decreased from immature stage to green mature stage and increased from green mature stage to mature stage. The climacteric peak of respiration rate appeared when the whole fruit was colored and the respiration rate was decreased thereafter.

15. The pigment contents in fruits stored in carbon di-oxide were lower than those of fruits stored in oxygen.

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