Adaptability of Citrus Species Based on the Relationships between Climatic Parameters and Fruit Quality Characteristics¹

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Summary

In the majority of middle and late maturing citrus species and cultivars, the relationships between climatic parameters including temperature, precipitation, sunshine and solar radiation, and morphological characteristics and inherent quality of the fruit, for which data were collected from many locations in Japanese citrus growing areas during several years, were analyzed by single and multiple regression analysis. The objective of the investigation was to determine the range of variations in temperature, precipitation, sunshine and solar radiation in the citrus growing areas where citrus fruits of distinctive quality are produced.

Temperature is the climatic factor which was found to have greatest effect on fruit quality characteristics, in particular the citric acid content, Brix/acidity ratio, juice pH, rind thickness, flesh percentage, shape index of fruit and fruit weight. The parameters related to temperature included the annual mean temperature, mean temperature from Apr. to Nov. and annual effective cumulative temperature.

Rainfall was also found to significantly affect several fruit quality characteristics. Contradictory results were obtained for relationships between the precipitation and the citric acid content in juice. These disagreements may be ascribed to the interaction of factors including the duration of rainfall, the rainfall intensity in each period and the development and maturation period of fruit.

The changes observed in the fruit quality characteristics related to the climatic parameters did not correspond to variations in the Brix values but corresponded to variations in the citric acid content and the Brix/acidity ratio.

Five multiple regressions among the fruit quality characteristics (Dependent variable) and the climatic parameters (Independent variable) were obtained. The climatic conditions associated with a high fruit quality in 8 citrus species and cultivars, based on the relationships obtained from the regression lines, were tabulated.

The relationships between mean monthly temperature, monthly duration of sunshine and monthly solar radiation were highly significant. In further investigations, the annual cumulative solar radiation should be determined to assess the adaptability of citrus species.

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Introduction

In Japan, a large number of middle and late maturing species and cultivars belonging to the genus *Citrus* have been extensively planted. Climatic problems associated with fruit quality tend to be more serious in some areas than in others. There is much evidence(1, 4, 6, 8, 9) suggesting that the meteorological conditions in the citrus growing areas are the most important factors influencing fruit quality. As a result, variations in fruit quality due to climatic conditions are generally greater than the variations among orchard in the same area.

Data, covering climatic conditions and fruit quality of the major species and cultivars in Japan, were collected from many locations in the citrus growing areas over a number of years. The relationships between climatic parameters, including temperature, precipitation, sunshine and solar radiation, and morphological and inherent fruit quality, as reflected in the Brix values and citric acid content, were analyzed by single and multiple regression analyses. As a result, a range of variations in temperature, precipitation, sunshine and solar radiation in the growing areas where citrus fruits of distinctive quality are produced were identified.

Rootstock and cultural practices, soil and topographical conditions of citrus orchards, etc. are factors that influence the morphology and inherent quality of the fruits produced in a citrus growing area.

In the citrus growing regions of Japan, analysis of the climatic conditions is considered to be a good method for determining the suitability of a citrus growing area where quality fruits of middle and late maturing species are cultivated.

Correlations and single and multiple regressions between the fruit quality characteristics and the meteorological variables were mathematically analyzed in 3 surveys.

Materials and Methods

1. 1979 survey

Medium size fruit of Hassaku (*C. hassaku* Hort. ex. Tanaka), Iyo and 'Miyauchi' Iyo

1. Odawara(1)(2)(3)*	17. Kohchi(2)
2. Inatori(1)(2)	18. Mihara(2)
3. Okitsu(1)(2)	19. Ohshima(2)
4. Shimizu(2)	20. Kunisaki(2)
5. Mitsukabi(2)	21. Tsukumi(2)
6. Gamagori(2)	22. Nango(2)
7. Tsu(3)	23. Fukuoka(1)(2)
8. Kumano(3)	24. Saga and Ogi(2)(3)
9. Owase(2)(3)	25. Ohmura(2)
10. Arita(1)(2)	26. Kuchinotsu(2)
11. Kokawa(2)	27. Matsuhashi(2)
12. Katsura(2)	28. Noda(3)
13. Sakaide(2)	29. Ibusuki(3)
14. Iwaki(2)	30. Tarumizu(1)(2)(3)
15. Matsuyama(1)(2)	31. Yaku-shima(2)
16. Yoshida(2)	32. Ogasawara(2)

Fig. 1. Locations surveyed.

* (1) Survey in 1979.

(2) Survey on the data published in 1974-79.

(3) Survey on the joint investigations from 1981 to 1983.

(*C. iyo* Hort. ex. Tanaka) and Ponkan (*C. reticulata* Blanco) were harvested in late Dec. 1979 at the 6 Citrus Experiment Stations shown in Fig 1-(1) and were transported to the University of Tsukuba from Jan. to Feb. in the following year.

In Tsukuba, the morphological characteristics of the fruit, including specific gravity, rind color and thickness, flesh percentage and shape index of fruit, and juice quality, including pH, specific gravity, Brix values and citric acid content were assessed.

Data on daily temperature, daily duration of sunshine and daily precipitation collected at the 6 stations from Apr. to Nov., 1979 were used and the annual duration of sunshine, mean temperature from Apr. to Nov.,

annual precipitation and annual effective cumulative temperature, were calculated.

Annual effective cumulative temperature calculated from following.

Annual effective cumulative temp.

$$=(T_{\text{mean}}i-10^{\circ}\text{C})Ni$$

where

T_{mean} = Monthly mean temperature

N = Number of days in a month

i = Months with mean temperature
10°C

2. Analysis of the data published in the period 1974~1979

It was considered that if the values for the parameters relating to fruit quality characteristics in the published data were reviewed and the corresponding values for certain limited orchards as well as the data on harvesting time of each year were utilized, a better correlation could be demonstrated between the fruit quality characteristics and the climatic parameters. In this survey, the data on fruit quality characteristics in the period 1974~1979 were analyzed 1) on the basis of the results published from 26 Citrus Experiment Stations as shown in Fig.1-(2), 2) in limiting the data to standard cultured trees in long-term field experiments in each station, and 3) in limiting the studies on trees on trifoliate orange and fruits to with 2 months after optimum harvesting time.

The citrus species and cultivars which were surveyed were 'Washington', 'Morita', 'Suzuki' and 'Yoshida' navel orange, 'Fukuhara' orange (*C. sinensis* Osbek), Hassaku, 'Miyachi' Iyo, 'Seminole' tangelo (*C. paradisi* × *C. reticulata*), 'Kara' mandarin (*C. unshiu* × *C. nobilis*), Ponkan, Hyuganatsu (*C. tamurana* Hort. ex. Tanaka) and 'Kawano' natsudaidai (*C. natsudaidai* Hayata).

The fruit quality characteristics (predictor variables) assessed included citric acid content, Brix values and Brix/acidity ratio, while the climatic parameters (criterion variables) consisted of the annual effective cumulative temperature, annual mean temperature, mean temperature from Apr. to Nov., from Apr. to May, from June to Aug. and Sept. to Nov., precipitation from Apr. to Nov. and the mean diurnal temperature

range from Apr. to Nov., from Apr. to May, from June to Aug. and from Sept. to Nov. Because the criterion variables including missing values were omitted, degrees of freedom of each predictor variable were 7~9.

3. Joint investigations at 4 locations from 1981 to 1983

Exchange of information of data collected during the surveys involved the following locations: Odawara, Mie (Kumano, Owase and Tsu), Saga and Kagoshima (Tarumizu, Noda and Ibusuki) which are shown in Fig. 1-(3). These locations corresponded to the north-eastern, central, south-western and southern part of the Pacific coast in Japan. Cultural practices and soil and topographical conditions of the orchards which were investigated in detail are not shown in this paper.

The climatic parameters and the fruit quality characteristics used are shown as X_1 - X_{11} and Y_1 - Y_7 in Fig.4. The duration of sunshine and the amount of solar radiation at each location were determined using a Jordan's sunshine recorder and a pyranometer or integrating pyranometer, respectively.

At each location, fruits of 'Miyagawawase' satsuma mandarin (*C. unshiu* Marc. var. *praecox* Tanaka) were harvested and analyzed in the middle of Oct., fruits of Hassaku, 'Miyachi' Iyo and 'Morita' and 'Washington' navel oranges were harvested and analyzed in early Dec., and fruits of 'Marsh' and 'Duncan' grapefruits and 'Kawano' natsudaidai were harvested and analyzed in early Feb. For each species and cultivar, 15~20 medium sized fruits were sampled. The rind color was evaluated using a "Standard color chart" which was prepared for orange color at the Fruit Tree Research Station. The citric acid titration in juice was performed using 0.1 N-NaOH the specific gravity and the pH of juice were determined using a baume specific weight meter and glass-electrode pH meter respectively and the Brix values in juice were determined using a digital refractometer.

Results

1. 1979 survey

Results of tests on the differences among

Table 1. Effect of citrus production area on the fruit quality characteristics surveyed in 1979.

	Fruit juice				Fruit characteristics				
	pH	Specific gravity	Brix (%)	Citric acid (%)	Shape index	Specific gravity	Rind thickness (mm)	Flesh percent. (%)	Rind color
Hassaku									
TA ^y	3.47ab ^z	1.041d	9.2b	1.28c	1.26ab	0.79c	9.2a	65	6.0a
FU	3.27c	1.042d	9.8bc	1.78a	1.21bc	0.86a	6.6b	71	5.4b
MA	3.47ab	1.048a	10.7a	1.37bc	1.20c	0.83b	7.4b	62	6.0a
ARI	3.60a	1.043cd	9.6cd	1.44bc	1.21dc	0.75d	9.2a	59	6.0a
OKI	3.38bc	1.042d	9.2d	1.38bc	1.28a	0.81bc	8.6a	66	6.0a
INA	3.37bc	1.045bc	9.7ba	1.49b	1.23abc	0.80c	5.1c	64	6.0a
ODA	3.35bc	1.046bc	10.1b	1.51b	1.26ab	0.83b	7.7b	66	5.6b
P	0.05	0.01	0.01	0.01	0.05	0.01	0.01	ns	0.05
Iyo									
TA	3.91a	1.048a	10.3b	1.36c	1.17	0.80a	5.2e	69a	8.0b
FU	3.27c	1.043b	9.6c	1.76a	1.14	0.72bc	6.9c	60bc	8.0b
MA	3.74ab	1.051a	11.1a	1.73ab	1.13	0.67c	7.8b	56c	10.0a
OKI	3.67b	1.049a	11.0a	1.49bc	1.18	0.77a	6.3d	65ab	9.8a
INA	3.59b	1.050a	10.9ab	1.67ab	1.20	0.76ab	8.1a	60bc	7.4b
P	0.01	0.01	0.01	0.01	ns	0.01	0.01	0.01	0.01
'Miyauchi' Iyo									
MA	3.68b	1.048b	10.6b	1.44	1.37a	0.72c	6.5ab	67c	9.2
ARI	3.51d	1.053a	11.8a	1.24	1.22c	0.69c	6.1abc	66b	9.0
OKI	3.91a	1.049b	10.6b	1.19	1.12d	0.77b	6.8a	66d	9.6
INA	3.67b	1.049b	10.6b	1.18	1.28b	0.78b	5.1bc	72b	9.2
ODA	3.57b	1.048b	10.1b	1.26	1.27b	0.84a	4.7c	75a	10.2
P	0.01	0.01	0.01	ns	0.01	0.01	0.01	0.01	ns
Ponkan									
MA	3.91b	1.049b	11.3b	1.29a	1.19b	0.82b	3.7a	69bc	9.0a
ARI	4.07ab	1.053a	12.8a	0.98ab	1.12b	0.72b	4.4a	67c	8.8a
OKI	3.93b	1.047bc	10.7bc	0.79bc	1.32a	0.78a	4.1ab	69bc	7.4b
INA	4.54a	1.043d	10.0d	0.48c	1.15b	0.82a	3.6b	73ab	7.8ab
ODA	4.57a	1.045cd	10.3cb	0.54c	1.34a	0.83a	3.6b	77a	8.6ab
P	0.05	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.05

^z Different letters within a column represent significant differences according to Duncan's multiple range test ($P < 0.01$ or < 0.05).

^y TA; Tarumizu, FU; Fukuoka, MA; Matsuyama, ARI; Arita, OKI; Okitsu, INA; Inatori, ODA; Odawara.

mean values of fruit quality characteristics are presented in Table 1. Correlations between fruit quality characteristics showing significant differences at $P < 0.05$ or $P < 0.01$ among the 7 locations listed in Table 1 and the climatic parameters in the respective locations were calculated the combinations showing significant correlations also being determined by regression. The results are shown in Fig. 2. A large number of significant differences in the values of fruit quality characteristics were detected at each location as the size of the fruits collected was not uniform. The combinations with highly significant correlations and their regression equations are

shown in Fig. 2.

It can be seen that in Hassaku the citric acid content in juice was negatively correlated with the effective cumulative temperature. In Iyo higher effective cumulative temperature and mean temperature from Apr. to Nov. resulted in the production of fruits with a lower citric acid content, higher juice pH, thinner rind and higher flesh percentage. In 'Miyauchi' Iyo the shape index of the fruit as represented by the width/length ratio was positively correlated with the duration of sunshine from Apr. to Nov., while in Ponkan the citric acid content in juice was negatively correlated with the pre-

Fig. 2. Regression lines showing the relationships between the fruit quality characteristics of late maturing citrus species and the climatic parameters in 1979.

Y_1 ; Citric acid (g/100g)

Y_2 ; Juice pH

Y_3 ; Rind thickness (mm)

Y_4 ; Flesh percentage (%)

Y_5 ; Shape index of fruit (width/length)

X_1 ; Annual effective cumulative temp. ($^{\circ}\text{C}$)

X_2 ; Mean temperature from Apr. to Nov. ($^{\circ}\text{C}$)

X_3 ; Duration of sunshine from Apr. to Nov. (h)

X_4 ; Precipitation from Apr. to Nov. (mm)

cipitation from Apr. to Nov.

Neither the specific gravity and Brix values of juice as indices of the soluble solid content nor the specific gravity and flesh percentage of fruit were correlated with the climatic parameters.

2. Survey using the data published in the period 1974~1979

In Hyuganatsu 'Kara' mandarin, 'Kawano'

natsudaidai and 'Fukuhara' orange, the results showed negative correlations between the fruit quality characteristics and the climatic parameters owing to the small number of locations and years investigated.

Combinations showing highly significant correlations and their regression equations by year and shown in Fig. 3. In Hassaku the citric acid content in juice was negatively cor-

Fig. 3. Regression lines showing the relationships between the fruit quality characteristics of late maturing citrus species and the climatic parameters in the period 1974-79.

Y_1 : Brix ($^{\circ}$)

Y_2 : Citric acid (g/100g)

Y_3 : Brix/acidity ratio

X_1 : Annual mean temperature ($^{\circ}$ C)

X_2 : Annual effective cumulative temperature ($^{\circ}$ C)

X_3 : Mean temperature from Apr. to Nov. ($^{\circ}$ C)

X_4 : Mean temperature from Apr. to May ($^{\circ}$ C)

X_5 : Mean temperature from June to Aug. ($^{\circ}$ C)

X_6 : Mean temperature from Sept. to Nov. ($^{\circ}$ C)

X_7 : Precipitation from Apr. to Nov. (mm)

X_8 : Mean diurnal temperature range from Apr. to May ($^{\circ}$ C)

X_9 : Mean diurnal temperature range from June to Aug. ($^{\circ}$ C)

X_{10} : Mean diurnal temperature range from Sept. to Nov. ($^{\circ}$ C)

related with the annual effective temperature. In 'Seminole' tangelo it was negatively correlated in 1874 and positively correlated in 1977 with the mean temperature from Apr. to Nov. In 1977 the citric acid content in juice was negatively correlated in Iyo 'Miyachi' Iyo and Ponkan and positively correlated in 'Washington' and 'Yoshida' navel oranges and Ponkan with the precipitation from Apr. to Nov. The relationships between the citric acid content in juice and precipitation from Apr. to Nov. varied according to the monthly precipitation during this period.

The Brix values in juice showed no significant correlation with climatic parameters. However, a positive correlation was observed between the Brix values in 'Suzuki' navel orange and both annual effective temperature and annual mean temperature. There was a negative correlation between the Brix values in Hassaku fruit and the mean diurnal temperature range from Apr. to Nov. and from June to Aug.

In 'Seminole' tangelo the Brix/acidity ratio in juice was positively correlated with the annual effective cumulative temperature, annual mean temperature and mean temperature from Apr. to Nov. and Apr. to May. In Ponkan it was negatively correlated in 1977 and positively correlated in 1979 with the precipitation from Apr. to Nov., and in Hassaku it was negatively correlated with the precipitation from Apr. to Nov.

A dependent variable, such as the citric acid content in juice, showed high correlation coefficients and regressions with various climatic parameters (independent variables), but a multiple regression with the climatic parameters could not be fitted.

3. Joint investigations and exchange of data and information at 4 locations

At every location, the methods of determining the quality characteristics of fruits and the studies on the climatic parameters used in the survey were as uniform as possible and were continued over a period of 3 years. The combinations which showed significant coefficients of correlation between the fruit quality characteristics and the climatic

parameters and their single regressions are shown in Table 2 along with the significant combinations at $P < 0.10$.

In 'Miyagawa-wase' satsuma mandarin and 'Kawano' natsudaïdai, the fruit quality characteristics showed no significant correlations with the climatic parameters. However, in 'Kawano' natsudaïdai, a positive correlation was found between the citric acid content in juice and mean temperature from Apr. to Nov.

In Hassaku, the Brix/acidity ratio in juice was negatively correlated with the mean temperature from Apr. to Nov. The shape index of 'Miyachi' Iyo fruit showed significant correlations with several climatic parameters, in particular, there was a positive correlation with factors related to the temperature and negative correlation with the precipitation from Sept. to Nov. The rind color of the fruit showed a negative correlation significant at $P < 0.01$ with the precipitation from Sept. to Nov., indicating that the rich orange-red color became more pronounced due to the light rainfall during the ripening period of the fruit.

In grapefruit, the citric acid content in juice, the fruit weight and the flesh percentage showed high correlations with the factors related to temperature. The citric acid content in juice decreased while the fruit weight and flesh percentage increased with an increase in the cumulative temperature.

The fruit quality characteristics of navel orange were significantly correlated with the various climatic parameters. Of the 77 combinations, 26 were significant at $P < 0.10$, 7 were significant at $P < 0.05$ and 1 was significant at $P < 0.01$. The constituents of juice were not significantly correlated with the climatic parameters, except citric acid content which was positively correlated with the duration of sunshine from Apr. to Nov. With regard to the physical characteristics of fruit, there were negative correlations between the fruit weight and amount of solar radiation, between the rind color and the factors related to precipitation and between the shape index of fruit and the duration of sunshine.

In this survey there was no high correla-

Table 2. Relationships between the fruit quality characteristics of citrus species and cultivars and the climatic parameters in the joint investigation from 1981 to 1983.

Combination of highly significant correlations				
Dependent variable	Independent variable	Correlation coefficient (r)	P	Regression equation
'Miyagawa-wase' satsuma mandarin...in 77 combinations				
Y_1^z	X_6^y	-0.558	0.10	
Y_1	X_{11}	0.662	0.10	
Y_2	X_6	0.578	0.10	
Y_3	X_6	-0.560	0.10	
Hassaku...in 77 combinations				
Y_1	X_1	-0.468	0.10	
Y_3	X_3	-0.544*	0.05	$Y_3=15.44-0.4058X_3$
Y_4	X_2	0.474	0.10	
Y_4	X_6	-0.619	0.10	
Y_4	X_9	0.597	0.10	
Y_4	X_{11}	0.669	0.10	
Y_5	X_9	-0.701	0.10	
Y_6	X_1	0.620*	0.05	$Y_6=0.9539+0.01667X_1$
Y_6	X_2	0.524	0.10	
Y_6	X_3	0.610*	0.05	$Y_6=0.8259+0.01933X_3$
'Miyauichi' Iyo...in 74 combinations				
Y_2	X_{10}	-0.661	0.10	
Y_4	X_2	0.483	0.10	
Y_4	X_3	0.474	0.10	
Y_5	X_4	-0.649	0.10	
Y_5	X_5	-0.792	0.10	
Y_5	X_7	-0.935**	0.01	$Y_5=9.831-2.533 \times 10^{-3}X_7$
Y_6	X_1	0.687*	0.05	$Y_6=0.7276+0.02722X_1$
Y_6	X_2	0.600*	0.05	$Y_6=0.8066+1.446 \times 10^{-4}X_2$
Y_6	X_3	0.774**	0.01	$Y_6=0.3659+0.03930X_3$
Y_6	X_7	-0.663*	0.05	$Y_6=1.216-9.173 \times 10^{-5}X_7$
Y_6	X_9	-0.654	0.10	
Y_6	X_{10}	0.649	0.10	
'Washington' and 'Morita' navel orange...in 77 combinations				
Y_2	X_8	0.795	0.10	
Y_2	X_9	0.839*	0.05	$Y_2=0.7594+4.385 \times 10^{-4}X_9$
Y_2	X_{10}	-0.646	0.10	
Y_3	X_4	0.609	0.10	
Y_3	X_5	0.569	0.10	
Y_3	X_6	0.591	0.10	
Y_3	X_8	-0.671	0.10	
Y_3	X_9	-0.795	0.10	
Y_3	X_{10}	0.675	0.10	
Y_4	X_8	0.648	0.10	
Y_4	X_9	0.685	0.10	
Y_4	X_{10}	-0.848*	0.05	$Y_4=471.8-2.287 \times 10^{-4}X_{10}$
Y_4	X_{11}	-0.811*	0.05	$Y_4=562.3-4.232 \times 10^{-4}X_{11}$
Y_5	X_4	-0.857*	0.05	$Y_5=12.20-1.815 \times 10^{-3}X_4$
Y_5	X_5	-0.858*	0.05	$Y_5=11.12-1.578 \times 10^{-3}X_5$
Y_5	X_6	-0.698	0.10	
Y_5	X_7	-0.748	0.10	
Y_6	X_1	0.541	0.10	
Y_6	X_9	-0.958*	0.05	$Y_6=1.176-1.080 \times 10^{-4}X_9$

(Table 2. Continued from former page)

Combination of highly significant correlations				
Dependent variable	Independent variable	Correlation coefficient (r)	P	Regression equation
Y_6	X_{10}	0.848	0.10	
Y_7	X_1	-0.463	0.10	
Y_7	X_3	-0.540	0.10	
Y_7	X_4	0.735	0.10	
Y_7	X_5	0.673	0.10	
Y_7	X_{10}	0.877*	0.05	$Y_7=66.33+1.149\times10^{-5}X_{11}$
Y_7	X_{11}	0.669	0.10	
'Marsh' and 'Duncan' grapefruit...in 48 combinations				
Y_1	X_5	0.650	0.10	
Y_1	X_6	0.820	0.10	
Y_2	X_1	-0.669	0.10	
Y_2	X_2	-0.729	0.10	
Y_2	X_3	0.596	0.10	
Y_2	X_7	0.771	0.10	
Y_4	X_1	0.682	0.10	
Y_4	X_2	0.636	0.10	
Y_4	X_3	0.810*	0.05	$Y_4=-480.9+37.05X_3$
Y_4	X_5	-0.836	0.10	
Y_6	X_5	-0.761	0.10	
Y_7	X_1	0.977**	0.01	$Y_7=-45.56+6.972X_1$
Y_7	X_2	0.945*	0.05	$Y_7=10.05+0.02269X_2$
Y_7	X_3	0.946*	0.05	$Y_7=-27.98+4.692X_3$
'Kawano' natsudaikai...in 74 combinations				
Y_1	X_1	-0.482	0.10	
Y_1	X_9	-0.706	0.10	
Y_2	X_3	0.573*	0.05	$Y_2=-0.6451+0.1184X_3$
Y_3	X_3	-0.539	0.10	
Y_6	X_6	-0.731	0.10	
Y_7	X_{10}	0.746	0.10	

* Y_1 ; Brix (°)
 Y_2 ; Citric acid (% 100g)
 Y_3 ; Brix/acidity ratio
 Y_4 ; Fruit weight (g)
 Y_5 ; Rind color (1-10)
 Y_6 ; Shape index of fruit (width/length)
 Y_7 ; Flesh percentage (%)
* X_1 ; Annual mean temperature (°C)
 X_2 ; Annual effective cumulative temperature (°C)
 X_3 ; Mean temperature from Apr. to Nov. (°C)
 X_4 ; Annual precipitation (mm)
 X_5 ; Precipitation from Apr. to Nov. (mm)
 X_6 ; Precipitation from Apr. to Aug. (mm)
 X_7 ; Precipitation from Sept. to Nov. (mm)
 X_8 ; Annual duration of sunshine (h)
 X_9 ; Duration of sunshine from Apr. to Nov. (h)
 X_{10} ; Annual amount of solar radiation (kcal/m²)
 X_{11} ; Amount of solar radiation from Apr. to Nov. (kcal/m²)

tion coefficient with the Brix values in juice of any species or cultivar.
For the combinations showing a significant correlation over $P<0.05$, multiple regressions were calculated. Five multiple regressions showing a significant coefficient of determination (R^2) for the multiple correlation(R) are shown in Table 3.

Table 3. Multiple regression between the fruit quality characteristics and the climatic parameters in the joint investigation from 1981 to 1983.

Combination of highly significant multiple regression coefficients		
Multiple regression coefficient (R)	Ratio of contribution (R ²)	Multiple regression equation
Hassaku		
0.537**	0.288	$Y_6^z = 0.8729 + 9.858 \times 10^{-3}X_1 + 9.301 \times 10^{-3}X_3$
'Miyachi' Iyo		
0.746*	0.557	$Y_6 = 0.3507 + 0.01469X_1 - 3.503 \times 10^{-5}X_2 + 0.03278X_3$
'Washington' and 'Morita' navel orange		
0.872*	0.761	$Y_4 = 582.7 - 1.515 \times 10^{-4}X_{10} - 2.443 \times 10^{-4}X_{11}$
0.877*	0.769	$Y_5 = 10.60 + 3.726 \times 10^{-4}X_4 - 1.784 \times 10^{-3}X_5$
'Marsh' and 'Duncan' grapefruit		
0.996**	0.992	$Y_7 = -131.8 + 17.41X_1 - 0.03905X_2 + 0.7906X_3$

^z Y and X are the same as in Table 2.

^y Significant at $P < 0.01(**)$ or $< 0.05(*)$.

Table 4. Climatic conditions associated with high fruit quality in 8 citrus species and cultivars (Results obtained in regression lines shown in Fig. 2-4.).

(1) Hassaku

Characteristics	Desirable range of value	Mean temp. from Apr. to Nov.	Annual effective cumulative temp.	Mean diurnal temp. range		Precipitation from Apr. to Nov.
				From Apr. to May	From June to Aug.	
Brix	10°— ^z			—9°C	—8°C	
Citric acid	^y —1.4%		2,500—2,800°C**			—1,500mm
Brix/acidity ratio	7—					

(2) Iyo

Characteristics	Desirable range of value	Mean temp. from Apr. to Nov.	Annual effective cumulative temp.
Citric acid	—1.5%	20.5—21.5°C	2,500—2,800°C
Juice pH	3.5—	20.5—21.5	2,500—2,800
Rind thickness	—7mm	21—21.5	
Flesh percentage	60%—	20—	
	65%—	21—22	

(3) 'Miyachi' Iyo

Characteristics	Desirable range of value	Mean temp.		Annual effective cumulative temp.	Precipitation	
		Annual	From Apr. to Nov.		From Apr. to Nov.	From Sept. to Nov.
Citric acid	—1.5%				1,200—1,500mm	
Juice pH	3.6—		20—21.5°C			
Rind color	8—					—600mm
Shape index of fruit	1.2—	17—	21°C—	2,700°C—		—600
	1.15—	15.5—	20°C—	2,500°C—		—650

In 9 major species and cultivars, the climatic parameters of the growing area associated with the fruit quality characteristics are shown in Table 4. For example, in Iyo, fruits with high quality characteristics,

which are associated with a citric acid content of 1.5% or below, juice pH of 3.5 and above, rind thickness of 7 mm and below and flesh percentage of 60~65%, should be produced in a growing area where the mean

(4) Washington' and 'Morita' navel orange

Characteristics	Desirable range of value	Annual mean temp.	Annual effective cumulative temp.	Precipitation from Apr. to Nov.	Duration of sunshine from Apr. to Nov.	Amount of solar radiation	
						Annual	From Apr. to Nov.
Brix	11°— 12°—	16°C— 16.5°C—	2,600°C— 2,700°C—	(Their results were obtained in 'Suzuki' navel orange)			
Citric acid	—1.5%						
Fruit weight	200 g—			—1,600mm	—1,700 h	kcal/m ² 11 × 10 ⁵	850,000
Rind color	8—			—1,800 (Annual —2,200)			
Shape index of fruit	—1.02				1,400—		
Flesh percentage	78—82%					11 × 10 ⁵ —13 × 10 ⁵	

(5) 'Marsh' and 'Duncan' grapefruit

Characteristics	Desirable range of value	Mean temp.		Annual effective cumulative temp.
		Annual	From Apr. to Nov.	
Citric acid	—2.2% —2.1%	16.5°C— 18°C—		2,600°C— 3,000°C—
Fruit weight	300 g—	17°C—	21°C—	
Flesh percentage	70%—		21°C—	2,600°C—

(6) Ponkan

Characteristics	Desirable range of value	Precipitation from Apr. to Nov.	Mean diurnal temp. range	
			From Apr. to May	From Sept. to Nov.
Citric acid	—1.0%	1,500mm— —1,300 1,400—	—10.5°C	—10°C
Brix/acidity ratio	15—	—1,200 1,600—		

(7) 'Seminole' tangelo

Characteristics	Desirable range of value	Mean temp.			Annual effective cumulative temp.
		Annual	From Apr. to Nov.	From Apr. to May	From Sept. to Nov.
Citric acid	—1.5%				18.5°C—
Brix/acidity ratio	7—	16.5°C—	20.5°C—	17.5°C—	2,600°C—

^z 10°—: 10 and above ^y —1.5%: 1.5 and below ^x occurs twice

temperature from Apr. to Nov. ranges from 20°C to 21.5°C and the annual effective cumulative temperature from 2,500 to 2,800°C.

Multiple regressions were obtained between the shape index of fruit of Hassaku and 'Miyauchi' Iyo, the fruit weight and rind color of navel oranges and the flesh percentage of grapefruit, and 2-3 climatic parameters. For example, the value of 79.24% for the flesh percentage of grapefruit corresponded to 17°C for the annual mean temperature(X_1), 2,699°C for the annual effective cumulative

temperature(X_2) and 21°C for the mean temperature from Apr. to Nov., respectively. Multiple regressions which were obtained for morphological characteristics of fruit could not be obtained for inherent fruit quality.

The correlations and single and multiple regression equations for monthly mean temperature, monthly duration of sunshine and monthly amount of solar radiation were calculated from the data obtained in the joint investigations from 1981 to 1983, and are shown in Table 5.

Table 5. Relationships among monthly amount of solar radiation, monthly mean temperature and monthly duration of sunshine in the meteorological data surveyed in 1981–83.

1. Single regression

Location or Month	Combination of highly significant correlations			
	Dependent variable	Independent variable	Correlation coefficient (<i>r</i>)	Regression equation
(1) On all data in the 7 locations for 3 years				
	Y^z	X_1^y	0.604***	$Y = 55552.9 + 2257.73X_1$
	Y	X_2	0.580**	$Y = 29736.8 + 367.42X_2$
(2) On all data from Apr. to Nov. in the 7 locations for 3 years				
	Y	X_1	0.444**	$Y = 48770.6 + 2562.42X_1$
	Y	X_2	0.638**	$Y = 39900.8 + 352.398X_2$
(3) On data in each location for 3 years				
Ibusuki	Y	X_1	0.933**	$Y = 27299.9 + 4698.53X_1$
	Y	X_2	0.952**	$Y = -16009.3 + 638.921X_2$
Tarumizu	Y	X_1	0.641*	$Y = 35239.1 + 2352.92X_1$
	Y	X_2	0.953**	$Y = 3396.2 + 487.39X_2$
Owase			Both n. s.	
Kumano	Y	X_1	0.697**	$Y = 6828.6 + 2148.11X_1$
	Y	X_2	n. s.	
Tsu	Y	X_1	0.717**	$Y = 56853.9 + 1881.7X_1$
	Y	X_2	0.688**	$Y = -31475.9 + 605.87X_2$
Odawara			Both n. s.	
Saga	Y	X_1	0.861**	$Y = 42741.8 + 2250.29X_1$
	Y	X_2	0.785**	$Y = -12689.6 + 507.18X_2$
(4) On monthly data in the 7 locations for 3 years				
Jan.	Y	X_1	n. s.	
	Y	X_2	0.721*	$Y = -7009.9 + 450.61X_2$
Feb.	Y	X_1	n. s.	
	Y	X_2	0.808**	$Y = 19847.9 + 347.62X_2$
March			Both n. s.	
Apr.			Both n. s.	
May			Both n. s.	
June			Both n. s.	
July	Y	X_1	0.771*	$Y = -171232 + 11184.7X_1$
	Y	X_2	0.762*	$Y = 63739.2 + 295.33X_2$
Aug.	Y	X_1	0.649*	$Y = -255569 + 13860.0X_1$
	Y	X_2	n. s.	
Sept.			Both n. s.	
Oct.	Y	X_1	n. s.	
	Y	X_2	0.671*	$Y = 24370.4 + 344.847X_2$
Nov.			Both n. s.	
Dec.	Y	X_1	0.641*	$Y = 34882.5 + 3328.99X_1$
	Y	X_2	n. s.	

In the yearly data, the monthly data from Apr. to Nov. at the 7 locations, there were a number of multiple significant correlation coefficients and significant multiple regression coefficients among the 3 elements, except for Odawara and the month of March, Apr., May, Aug., Sept. and Nov. This finding suggests that it is possible to regress the amount of solar radiation by the mean temperature or the duration of sunshine.

Discussion

Adaptability of citrus species and cultivars, should be reflected in high yield with annual bearing and distinctive quality of the fruit at a low cost. Most of the citrus species have been selected from subtropical regions. The growth habit and fruit quality characteristics of citrus are highly sensitive to light and temperature within a given environment, and the response to each factor varies with the citrus species and cultivar.

2. Multiple regression

(Table 5. Continued from former page)

Location or Month	Combination of highly significant multiple regression coefficients		
	Multiple regression coefficient (R)	Ratio of contribution (R ²)	Multiple regression equation
(1) On all data in the 7 locations for 3 years	0.721***	0.521	$Y = 9060.3 + 1768.43X_1 + 314.79X_2$
(2) On all data from Apr. to Nov. in the 7 locations for 3 years	0.699**	0.489	$Y = 9642.24 + 1817.34X_1 + 312.87X_2$
(3) On data in each location for 3 years			
Ibusuki	0.987**	0.968	$Y = -6529.96 + 2320.23X_1 + 382.773X_2$
Tarumizu	0.941**	0.886	$Y = 3917.30 - 171.080X_1 + 504.048X_2$
Owase	0.780**	0.609	$Y = -16438.3 + 2709.73X_1 + 451.123X_2$
Kumano	0.779**	0.626	$Y = -1450.45 + 2723.21X_1 + 355.379X_2$
Tsu	0.791**	0.626	$Y = -14040.1 + 1360.08X_1 + 412.741X_2$
Odawara	n. s.		
Saga	0.883**	0.779	$Y = 9648.77 + 1589.07X_1 + 243.13X_2$
(4) On monthly data in the 7 locations for 3 years			
Jan.	0.841**	0.707	$Y = -2758.8 + 3020.21X_1 + 462.081X_2$
Feb.	0.814**	0.662	$Y = 6396.45 + 1749.57X_1 + 362.017X_2$
March	n. s.		
Apr.	n. s.		
May	n. s.		
June	0.647*	0.418	$Y = 219091 - 7068.22X_1 + 277.638X_2$
July	0.726*	0.527	$Y = -77729.1 + 6493.81X_1 + 152.523X_2$
Aug.	n. s.		
Sept.	n. s.		
Oct.	0.672*	0.451	$Y = -22918.8 + 2527.77X_1 + 343.343X_2$
Nov.	n. s.		
Dec.	0.784*	0.614	$Y = -16172.1 + 4207.19X_1 + 256.907X_2$

* Y ; Monthly amount of solar radiation (kcal/m²)
^v X₁ ; Monthly mean temperature (°C)
X₂ ; Monthly duration of sushine (h)
* Significant at P<0.01 (**) or <0.05 (*)
n. s. ; Abbreviation for non significance

In this study, correlations and single and multiple regressions between the fruit quality characteristics of major citrus species and cultivars and the climatic parameters in the citrus growing areas were analyzed.

In relation to the climatic adaptability of trees in the citrus growing areas, Nakagawa (4) investigated the climatic conditions of citrus growing areas in Japan and overseas and determined the suitable effective cumulative temperature and extremes of low temperature and frequency in the growing area of satsuma mandarin for storage, 'Natsudaidai', Ponkan, 'Washington' navel orange, 'Valencia' orange, lemon and grapefruit. He also suggested that the daily mean temperature should be taken as a basis when the effective

temperature affecting the growth of the tree and the development and maturation of fruit are determined. In the current study the same method was adapted.

Temperature is the climatic factor that most affects fruit quality characteristics. Several authors(3, 5, 9) have analyzed the effect of temperature upon each of the quality characteristics and the maturation of fruit on tree, using several methods including the sum of degrees per day. The relationships between fruit quality characteristics and factors relating to temperature which were observed in our surveys showed a similar tendency. The fruit quality characteristics which were particularly affected included citric acid content, Brix/acidity ratio, juice pH,

rind thickness, flesh percentage, shape index of fruit and fruit weight. Among the temperature parameters the most important ones were the annual mean temperature, mean temperature from Apr. to Nov. and annual effective cumulative temperature.

Sanchez Garcia and Fernandes (8) stated that in the tropical climate of Cuba, temperature and rainfall during the two months preceding harvest affected the peel thickness, fruit shape, total soluble solid, soluble solid/acid ratio and acidity, which should be considered as basic characteristics in determining the fruit quality. Rainfall was observed to have the most significant effect on the first 2 characteristics, while temperature had the most effect on the last 3 characteristics.

This report showed contradictory results in the relationships between the precipitation from Apr. to Nov. and the citric acid content of Ponkan fruit (Table 4(6)). Such disagreement could be ascribed to the interaction of factors including the development and maturation period of fruit.

Reuther *et al* (6) studied 'Valencia' orange in four different climatic areas in the USA and found differences in peel thickness that were related to the prevailing temperature and humidity conditions in each region. In our study these findings only agree with the results obtained in Iyo.

As expected, the maturity index of the fruit, was correlated with the Brix values and citric acid content in juice. Changes observed in the fruit quality characteristics related to the climatic parameters did not correspond to the variations in the Brix values but correspond to the variations in the citric acid content and the Brix/acidity ratio.

The variations in fruit quality characteristics which were found to be associated with the temperature could be more significantly correlated with the effective cumulative radiation controlling the total photosynthetic rate of the citrus trees. In this report, the fruit weight of navel orange only showed a significant regression with the amount of solar radiation.

Except for some locations and a few months the relationships between mean monthly

temperature, monthly duration of sunshine and monthly solar radiation were highly significant. The annual cumulative amount of solar radiation should be determined in similar and future investigations to assess the adaptability of citrus species.

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気象要素と果実品質変動の関係とカンキツの適地性について

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摘 要

わが国のカンキツ生産各地における気象要素，すなわち温度，降水量，日照，日射と主要な中晩生カンキツの果実品質値とを調査もしくは収集し，その間の回帰並びに重回帰解析を行うことによって，良好な品質の果実生産地の気象要素の範囲を知ろうとした．

温度は果実品質変異に最も影響するが，なかでもクエン酸含量，甘味比，果汁 pH，果皮厚，果肉率，果形指数，果重が変異し，温度に関する測定項目としては，年及び4～11月の平均温度，有効積算温度の影響が強い．

雨もまた，果実品質に有意な影響を与えることを見出したが，とくにクエン酸に，果実発育，成熟の時期別の降水強度によって相矛盾した結果が現れる．

果実品質中，果汁の Brix はクエン酸や甘味比ほど気象要素に感応しない．

各果実品質項目を従属変数として各気象要素を独立変数とする重回帰は5式得られた．また，得られた単回帰式と重回帰式から，良好な品質の各中晩生カンキツ果実の得られる気象要素の範囲を提示した．

4 大学連絡調査結果(1981～1983)から，月平均温度，月日照時数及び月日射量との間に高い相関があり，回帰関係が成立する．光合成能と日射量との関係から考えて，有効積算温度と同様に有効積算日射量による適地判定が考慮されなければならない．