温州ミカンの品質支配要因の寄与度に関する研究(I)

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Studies on the Contribution of Environmental and Internal Factors Affecting the Edible Quality and Exterior Appearance of Satsuma Mandarin Fruits

I. Estimation of the Contribution of Some Factors Influencing the Total Soluble Solids and Free Acid Content of Juice

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Summary

The contribution of several factors affecting the total soluble solids and free acid content of *satsuma* fruit was estimated by the quantification method. The orchard location gives the greatest contribution to both the refractive index and total acidity of flesh juice. As for the total soluble solids content, the contribution of slope exposure ranks second, followed by tree age. In general, the refractive index of the juice increases slightly but consistently with increase in tree age. Altitude and distance factors exert less effects on the solids content than the other factors.

On the other hand, the total acidity of the juice increases considerably as the grove departs farther from the coast line. As for the altitude, the acidity increases outstandingly at higher levels than 200 meters above the sea, though at lower levels than this limit it is scarcely influenced by altitude. Exposure of the slope exerts somewhat irregular effects on both solids and acid content of the juice.

Introduction

During recent years the standard of Japanese living has been elevated outstandingly year after year, and an expanding demand by consumers for living necessaries has stimulated the production of various fruits on an enlarged scale. In this situation both the growers' and consumers' prices vary widely, depending on the internal and external qualities of fruit produced. Thus, successful growers must exert special efforts to produce fruit of high quality to meet the requirement of the fresh fruit market, and hence have to pay greater attention to all the environmental factors and managerial practices concerned.

Fruit quality, however, is inevitably affected by various factors throughout the entire process of fruit development. Thus it seems quite difficult to control the quality of fruit which can be realized only after the completion of all the processes, which, when integrated, determin quality at maturity. So as to provide better insight into this problem, the contribution of various governing factors should first be estimated. Thus far, regression and correlation coefficients have been assessed as indices of contributions of environmental factors by Hoshino *et al.*(10), Oohata *et al.*(16), Sakamoto *et al.*(19, 20), and Yamaguchi *et al.*(23). Beside these, the product of the simple correlation coefficient by the standard partial regression coefficient, a kind of coefficient of determination, can be employed for estimating the contribution of the factors under investigation. In this paper, this product is referred to as the 'coefficient of partial determination'.

These coefficients, however, are not known to be the best for the estimation of the contribution, since they are calculated under the assumption that when quantitative data are used, the characteristics concerning the contributing factors have a linear relation with labels of elements in the population. In the strict sense, such an assumption is scarcely, true, as a generalization, for most biological

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phenomena. As implied by the principle of limiting factors, the relations between biological effects and characteristics concerning contributing factors are not always linear but, in some cases, non-linear ones such as parabolic, exponential, logarithmic, and so on. Sometimes they may even be bi-modal curves. Thus, the statistical fit of non-linear data to a simple linear model may inevitably augment the residual variance, because the variance due to the non-linear part of the regression, *i. e.*, the deviation of curvi-linear data from the straight line, will be involved in the error component.

On the other hand, another difficult problem is that the contribution sometimes must be determined from qualitative observations, and size classes or categories must be defined not by numerical or quantitative values but by qualitative characteristics. From sets of such qualitative characteristics, however, the contribution expressed in terms of the partial regression coefficient or the coefficient of partial determination cannot be estimated. In order to avoid these troublesome problems, the so-called 'theory of quantification' developed by Hayashi(5, 6) can be applied successfully in the procedure of the estimation of contributions. In this procedure, the quantitative and qualitative characteristics both can be combined in the same multiple regression model. By this method, not only the estimation of contributions but also the descryption of the relation between labels of elements and characteristics concerning contributing factors can be made efficiently. Based on these advantages, a preliminary estimation of contribution of factors concerning the fruit quality of satsuma mandarin (*C. unshiu* Marc.) was undertaken by the quantification method.

Analytical Procedure

Sampling was made on November 20, 1966, covering 603 satsuma groves of different ages and various environmental conditions throughout the major citrus areas of Ehime. Nine representative fruits were selected for quality determination on three representative trees in each grove. Total soluble solids content of the juice was estimated by refractometer readings, and free acid content by titration. These indices (labels of elements) were employed as outside variable (criteria) in the model. Beside these, the corresponding observations on tree age, altitude, distance from the coast line, exposure of the slope, and orchard location were recorded. They were introduced in the model as contributing factors as shown in Tables 1 and 3.

Let n be the number of the sample elements, R be the number of items (factors), and Kj be the number of categories involved in the jth item. Then, we must choose the estimates of tjk (adjusted scores) so as to minimize the sum of squares of the residuals, *i. e.*,

$$\sum_{i=1}^{n} e_i^2=\sum_{i=1}^{n}(Y_i-\sum_{j=1}^{R}\sum_{k=1}^{Kj}\delta_i(jk)t_{jk})^2,$$

where Yi are labels of elements (outside criteria), and $\delta i(jk)$ are equal to unity when a given satsuma grove responds to the kth category in the jth item and otherwise equal to zero. The contribution of jth factor was defined by the range of the largest and smallest values of the adjusted scores in the jth item.

Furthermore, the partial correlation coefficient and the multiple correlation coefficient were calculated between labels of elements and adjusted scores of each item. Inner correlation matrices were necessarily obtained in the process of the calculation mentioned above.

An electronic computer, model HIPAC-103, was used in calculating the adjusted quantities and the correlation coefficients.

Results

Table 1 presents the adjusted scores concerning the total soluble solids content of the juice. The adjusted quantity means the relative values of contribution within each item. It may be a meaningful fact that a sum of the quantity given to the designated category of each item indicates the deviation of an actual soluble solids content from its modal class value 8, 9. Table 2 shows the contributions of each factor expressed in terms of the range of scores given to the categories in each item. The range of the largest and smallest scores within each item indicates the actual variation of refractometer readings due to the effect of contributing factor in question. Table 2, also presents the multiple correla-

Table 1. Adjusted category scores of each factor, with respect to the refractive index of the juice.

item (factor)	scores (t_{jk}) of each category				
tree age (years)	10> $t_{11}=-0.236$	11~15 $t_{12}=-0.042$	16~20 $t_{13}=-0.118$	21~30 $t_{14}=0.168$	31< $t_{15}=0.228$
altitude (m)	50> $t_{21}=-0.076$	51~100 $t_{22}=0.063$	101~150 $t_{23}=-0.012$	151~200 $t_{24}=0.101$	201< $t_{25}=-0.076$
distance from the coast line (m)	300> $t_{31}=-0.107$	300~1000 $t_{32}=0.091$	1001~4000 $t_{33}=0.052$	4001~12000 $t_{34}=-0.107$	12001< $t_{35}=-0.141$
exposure of the slope	north $t_{41}=-0.087$	northeast $t_{42}=-0.026$	east $t_{43}=-0.011$	southeast $t_{44}=0.149$	south $t_{45}=0.288$
	southeast $t_{46}=-0.073$	west $t_{47}=0.151$	nothwest $t_{48}=-0.174$	low flat $t_{49}=-0.218$	
location	Uwa $t_{51}=0.430$	Nishiuwa $t_{52}=0.523$	Kita $t_{53}=-0.379$	Iyo $t_{54}=-0.122$	Onsen $t_{55}=-0.060$
	Ochi $t_{56}=-0.015$	Toyo $t_{57}=-0.290$	Nakajima $t_{58}=-0.087$		

Table 2. Contributions, coefficients of partial and multiple correlations, and coefficient of partial determination of five factors, with respect to the refractive index of the juice.

factor	tree age	altitude	distance	exposure	location
contribution	0.464	0.177	0.248	0.506	0.902
partial correlation	0.24**	0.07	0.10*	0.20**	0.32**
partial determination (%)	5.7	0.3	1.8	4.6	11.7
multiple correlation	0.49**				

* Significant at 5% level ** Significant at 1% level

tion coefficient between the outside variable and five independent variables corresponding to five contributing factors, and the partial correlation coefficients between the outside variable and every independent variable for which the designated scores within each item were given. The coefficient of partial determination is expressed in terms of percentages. At a glance it is obvious that the trend shown in the order of influencing power of these factors generally coincides with that of partial correlation coefficients, though the contributions of two factors, tree age and exposure of the slope, rank in the inverse order of those of partial correlation coefficients.

All values of the partial correlation coefficients seem to be unexpectedly low. The multiple correlation coefficient is also of low value, 0.49, which implies that the regression of the five independent variables introduced in the model accounts for only a fourth of the variation of the outside variable. In other words, an unknown major factor or factors other than those five must be left out of consideration.

Among these contributing factors, the orchard location gives the greatest variation in outside criteria. The range of the largest and smallest scores of the location item is 0.9 in terms of refractometer readings. Exposure of the slope ranks second with the range of refractive index 0.51, followed by tree age with 0.46. The contributions of altitude and distance from the coast line are markedly less than those of the other factors. In general, the refractometer readings of the juice increase slightly but consistently with increase in tree age. On the other hand, the effect of altitude on the soluble solids content is somewhat irregular, whereas that of distance

Table 3. Adjusted category scores of each factor, with respect to the total acidity of the juice.

item (factor)	scores (t_{jk}) of each category				
tree age (year)	10> $t_{11}=0.012$	11～15 $t_{12}=0.038$	16～20 $t_{13}=-0.032$	21～30 $t_{14}=-0.010$	31< $t_{15}=-0.008$
altitude (m)	50> $t_{21}=-0.016$	51～100 $t_{22}=-0.005$	101～150 $t_{23}=-0.009$	151～200 $t_{24}=-0.019$	201< $t_{25}=0.048$
distance from the coast line (m)	300> $t_{31}=-0.085$	301～1000 $t_{32}=-0.016$	1001～4000 $t_{33}=-0.006$	4001～12000 $t_{34}=0.034$	12001< $t_{35}=0.073$
exposure of the slope	north $t_{41}=-0.010$	northeast $t_{42}=0.059$	east $t_{43}=0.006$	southeast $t_{44}=-0.017$	south $t_{45}=-0.018$
	southwest $t_{46}=0.009$	west $t_{47}=0.015$	northwest $t_{48}=-0.020$	low flat $t_{49}=-0.024$	
location	Uwa $t_{51}=-0.009$	Nishiuwa $t_{52}=0.042$	Kita $t_{53}=-0.121$	Iyo $t_{54}=0.117$	Onsen $t_{55}=0.167$
	Ochi $t_{56}=0.017$	Toyo $t_{57}=-0.064$	Nakajima $t_{58}=-0.148$		

from the coast line shows a uniform, gradual decrease. The farther the distance from the coast line, the lower becomes the soluble solids content. As for the exposure of the slope, the solids content seems to be higher on lands sloped toward the south, west, and southeast than on the land of northern and northwestern exposures. As was expected, refractometer readings of the juice are low on the low-lying flat lands as compared to those on terraced slopes. However, it is not generally understood that the refractive index of the juice is rather low on the slopes of south-western exposures where the soil may be maintained drier than on the slopes of the other exposures throughout the growing seasons of the year. On the other hand, the location of the grove notably affects the soluble solids content of the juice. The southern satsuma areas of Ehime where the shipment is usually earlier than the other growing areas produce fruit of more advanced maturity with higher solids content, whereas the elevated areas of low temperatures or the moist areas with less hours of sunshine produce fruit of low refractometer readings. More intense solar radiation gives the fruit more heat, which may result in the advancement of fruit maturity.

Table 3 shows the relative values of the contributions with respect to total acidity of the juice. As stated above, a sum of the quantity given to the designated category of each item indicates the deviation of an actual juice acidity from its modal class value 1.2. Tree age exerts a slight effect on the free acid content of the juice, while the acidity increases consistently as the distance from the coast line increases. As for the effect of altitude, the total acidity of the juice seems to be less influenced at lower levels than 200 meters above the sea. At higher levels than this limit, however, the acidity increases strikingly with increase in altitude. The exposure of the slope exerts irregular effects on the free acid content of fruit, but their contribution is relatively slight. On the other hand, the acidity of the juice is remarkably altered by the orchard location.

Incidentally, it is a noteworthy fact that the distance from the coast line is closely related with the altitude. In fact, it is numerically shown in this survey that the simple correlation coefficient between characteristics of both factors is +0.416. This value may imply that the distance of the grove from the coast line depends, more or less, on the increase in altitude. If the correlation coefficient between altitude and distance from the coast line amounts to an appreciable value, so adjusted quantities given to the category pattern must fluctuate according to the exclusion of a factor in question. The contributions given by recalculation are compared

Table 4. Discrepancy of factor contributions arising from the exclusion of selected factors from the model.

factor	contribution		
	A	B*	C**
tree age	0.700×1/10	0.683×1/10	0.713×1/10
altitude	0.671	—	1.037
distance	1.582	1.693	—
exposure	0.833	0.848	0.899
location	3.145	3.205	3.713

* Altitude factor was removed
** Distance factor was removed

with the original shown in the column A of Table 4. When the altitude factor was removed from the model, the contributions of the remaining factors were not influenced by recalculation. As a result of the exclusion of distance factor, however, the contribution of altitude was considerably increased.

Discussion

Appropriateness of the application of quantification theory to the stratified random sampling of a field survey has been substantiated by a series of researches carried on by Hayashi(1, 2, 3, 4, 5, 6, 7, 8). Nishizawa *et al.*(14) also applied this theory, successfully, to the estimation of site index of the forest stand. In the estimation procedure they determined the category scores so as to maximize the correlation coefficient between labels of elements and the sum of designated scores of all items. In the present survey, however, the adjusted scores were chosen so as to minimize the sum of squares of the residuals. Both procedures gave the same results.

The advantages of the quantification method as compared to those of correlation analysis were previously pointed out in Introduction of this paper. On the other hand, this method possesses a few but essential disadvantages These, of course, hold for correlation analysis, too. The first is that every quantity or statistic estimated by any statistical procedures resembles somewhat the image of an X-ray film which is not inherent in the entity but necessarily depends upon the procedure of photography and radiographic apparatus. With such a single image, reasonable conclusion can hardly be drawn immediately. Conscientious doctors may diagnose tuberculosis by taking tomograms as clues. Likewise, conscientious research workers should recalculate or reestimate on the basis of various models. Different combinations of various factors which are readily realized by the exclusion or addition of factors can diagnose the stability and generality of models to be examined.

The second disadvantage is that if undesirable linkages between factors exist, that is, if the correlation between two sets of characteristics concerning two given factors is substantial, the distribution of contributions among factors is subject, more or less, to the influence of chance fluctuations. In fact, the contribution of the influencing factors fluctuated somewhat among the items in the recalculation by the exclusion of the distance factor from the original model. If the fluctuation is pronounced, some of factors influential in causing the instability of solution of normal equations should be removed.

An instability of solution of this type was also observed when small sized samples were used. Concerning this problem Palmer(17) gave useful advice "......it occasionally happens that one of the equations is so nearly a multiple or submultiple of another that an exact solution becomes difficult if not impossible. In such cases the number of observation equations may be increased by making additional measurements on quantities that can be represented by known functions of the desired unknown." Let k ($\geqq 7$) be the number of contributing factors, then the sample size n is required to be more than $(k/2)\times 10$ from the viewpoint of field survey. If k is less than 7, the sample size is required to be more than five times as many number as that of categories of all times.

Nakashima *et al.*(12) concluded from their survey in Kanagawa that the free acid content in juice of satsuma mandarin fruit depends closely on the altitude of the orchard site above the sea, while the refractive index or total sugar content of the juice is not affected by the altitude of growing site. The acidity of the juice becomes inconsistently high at levels higher than 200 meters. These effects of altitude on the total acidity and refractive index of the juice quite agree with those of the present survey in Ehime. On the other hand, Kuriyama *et al.*(12) pointed out that under Fukuoka conditions satsuma gloves located from 200 to 350 meters above the sea produce rather superior fruit, because of temperature inversion phenomenon, as compared to that produced on low-lying land. Noro *et al.*(15), however, observed a similar tendency in Shizuoka to that of Kanagawa and Ehime. As for the exposure of the slope, Nakashima *et al.*(12) also pointed out that in combination with increasing site altitude, orchards exposed to the north produced fruit of higher acidity as compared to that produced on southern exposures. In Ehime, however, the exposure of the slope exerts unexpectedly irregular effects on the acidity of the juice. It is not clear whether this irregularity is primarily caused by non-random location of sampling sites or mainly caused by instability in calculating circumstances. Recalculation on the basis of different models must be pursued further.

Another unexpected result is that the contribution of orchard location is outstandingly high as compared to that of the other factors. The standards for the sampling and determination procedures were strictly applied to every location. So, the variation of the acidity and refractive index of the juice among the locations seems to be due not to chance fluctuations or analytical errors but to other unknown factors which have not yet been introduced in the present model. From the results concerning the effect of locations, it may be safely assumed that at the sites where fruit development is more advanced, satsuma groves produce fruit of higher refractive index. The progress of fruit maturation seems to depend more closely on the intensity and hours of sunshine than on the atmospheric temperature. Takechi *et al.*(21, 22) showed that if the wind dies away or is blowing at velocities less than 2 meters per second, the solar radiation gives much heat to the plant body and the temperature of fruit and leaves rises up to several degrees over the atmospheric temperature. This radiation effect holds for the fruit temperature. It was substantiated by Nii *et al.*(13). Reuther(18) also pointed out that conventional air temperatures are not useful measures of energy budgets available to maturing citrus fruits in various climates, but summations based on radiant temperatures are useful approximations. Thus, it can be safely deduced that satsuma groves which are favored by more intense solar radiation can produced fruit of more advanced maturity with lower acidity and higher refractive index.

Further surveys on the basis of new models in which new major factors are involved have already been undertaken with hopeful prospects.

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温州ミカンの品質支配要因の寄与度に関する研究（I）

果汁の可溶性固形物および遊離酸含量を左右する要因の寄与度の推定

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摘　要

温州ミカンの可溶性固形物と遊離酸含量に影響する樹令および立地要因の寄与度を，現象数量化の手法を用いて推定した。果汁の糖度計示度と滴定酸度のいずれに対しても，地域を表わす要因の寄与度が最大であつた。また，糖度については，傾斜方位の寄与度が2位，樹令の寄与度が3位であつた。一般に，樹令が増すほど少しずつではあるが着実に糖度が高まつている。標高と海岸からの距離が糖度に及ぼす影響は，他の要因に比べてかなり低かつた。

いつぽう，果汁の滴定酸度のほうは，海岸からの距離が遠くなるにつれてかなり増加した。標高と酸度の関係は，海抜 200 m 以上のところで酸度の増加が著しく，それ以下のところでは標高差の影響をほとんど受けていない。傾斜方位の影響については，糖度，酸度のいずれに対しても，部分的に常識と一致しない傾向が認められた。