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SHORT COMMUNICATION

Relationship between Fruit Shape and Acid Content in Different Parts of Citrus Fruits

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Summary

The relationship between the ratios of the transverse diameter to the longitudinal (D/L ratio) and titratable acidity in the axial direction was determined at harvest in 14 citrus cultivars and species with different shapes: 'Nichinan No. 1', 'Okitsu', 'Nankan No. 20', 'Kuno', and 'Aoshima' satsuma mandarin (*C. unshiu* Marc.); 'Miyauchi' iyo (*C. iyo* hort. ex Tanaka); Amakusa ([{*C. unshiu* Marc. × *C. sinensis* Osbeck} × *C. unshiu* Marc.] × [{*C. paradisi* Macf. × *C. reticulata* Blanco} × *C. clementina* hort. ex Tanaka]); 'Yoshida' ponkan (*C. reticulata* Blanco); 'Shiranui' ([*C. unshiu* Marc. × *C. sinensis* Osbeck] × *C. reticulata* Blanco); 'Valencia' and 'Delta' orange (*C. sinensis* Osbeck); 'Marsh' grapefruit (*C. paradisi* Macf.); lemon (*C. limon* Burm. f.); Hebezu (*C. sp.*). The D/L ratio was positively correlated with the mid-section/stylar end ratio of acid content (r=0.76). It seems that the more depressed globular the fruit shape, the higher the acidity at the mid-section.

Key Words: acid content, fruit shape, mid-section, stylar end.

Introduction

It is known that titratable acidity differs with fruit portions in citrus (Blondel, 1952; Hall, 1955; Moon et al., 2002; Shiraishi, 1970; Ting, 1969). The titratable acidity is higher at the mid-section than at the stem and stylar ends in orange (Ting, 1969) and in satsuma mandarin fruit (Moon et al., 2002; Shiraishi, 1970).

Citrus fruits have different shapes such as depressed globular, round and oval (Iwahori and Kadoya, 1999; Saunt, 2000). Techniques for the determination of fruit quality with automatic sorting machines that use infrared sensors have recently been developed (Akimoto, 1998; Kawano et al., 1993). Thus, it is important to know the relationship between the acid distribution pattern and fruit shape in determining the fruit acidity with such devices. We report that the difference in titratable acidity within the different portions of fruit is associated with citrus fruit shapes.

Materials and Methods

Plant materials

'Nichinan No. 1'(Harvest time is middle Oct.), 'Okitsu' (late Nov.), 'Nankan No. 20' (middle Dec.), 'Kuno' (early Nov.) and 'Aoshima' (early Dec.) satsuma mandarin (*C. unshiu* Marc.), 'Miyauchi' iyo (late Dec.) (*C. iyo* hort. ex Tanaka), 'Yoshida' ponkan (early Jan.) (*C. reticulata* Blanco) and lemon (*C. limon* Burm. f.) (middle Oct.) were obtained from the experimental farm of Ehime University; Amakusa (middle Dec.) ([{*C. unshiu* Marc. × *C. sinensis* Osbeck} × *C. unshiu* Marc.] × [{*C. paradisi* Macf. × *C. reticulata* Blanco} × *C. clementina* hort. ex Tanaka]), 'Shiranui' (middle Feb.) ([*C. unshiu* Marc. × *C. sinensis* Osbeck] × *C. reticulata* Blanco) from Ehime Prefectural Fruit Tree Experimental Station; Hebezu (middle Oct.) (*C. sp.*) from a private farm in Miyazaki Prefecture and 'Valencia' and 'Delta' orange (*C. sinensis* Osbeck) and 'Marsh' grapefruit (*C. paradisi* Macf.) originally imported from South Africa, California, and Florida, USA, respectively, were purchased from local markets in early November. Fruit without any defects in shape were selected from the imported varieties.

Ten to forty fruit were used for analysis. The ratio of the transverse diameter to the longitudinal length (D/L ratio) of fruit was measured with a digital caliper (MATSUI, Japan).

Juice collection and acid analysis

Pulps were divided into the stem end, mid-section, and stylar end; each corresponds to 25, 50, and 25% of total fruit weight, respectively. Juice was squeezed through cheesecloth by hand and filtered through filter paper. Samples were stored at −20 ℃ until analysis. Acid content of the juice sample was titrated by using NaOH with phenolphthalein as an indicator. The results were converted to citric acid equivalence.

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Table 1. The transverse diameter, longitudinal length and acid content in the axial direction of various citrus fruits with different shapes.

Kinds of fruit	Transverse Diameter (mm)	Longitudinal length (mm)	D/L ratio	Acid content (%)			Types[z]	M/S[y]
				Stem end	Mid-section	Stylar end		
Kuno	71.0 ± 2.0[x]	48.1 ± 1.3	1.47	1.16 ± 0.03	1.47 ± 0.03	0.91 ± 0.02	DBD	1.62
Nankan No.20	64.5 ± 1.0	46.3 ± 0.6	1.39	0.62 ± 0.03	0.83 ± 0.03	0.57 ± 0.03	DBD	1.46
Aoshima	78.1 ± 1.1	57.5 ± 1.1	1.36	0.92 ± 0.03	1.11 ± 0.03	0.73 ± 0.03	CBD	1.52
Nichinan No.1	74.3 ± 0.2	54.5 ± 0.2	1.36	1.43 ± 0.05	1.56 ± 0.05	1.18 ± 0.04	CBD	1.32
Okitsu	78.2 ± 1.7	59.1 ± 1.5	1.32	0.65 ± 0.03	0.80 ± 0.04	0.60 ± 0.02	CBD	1.33
Miyauchi	92.5 ± 1.0	72.7 ± 1.0	1.27	1.09 ± 0.03	1.43 ± 0.05	1.20 ± 0.03	DBC	1.19
Amakusa	87.4 ± 1.0	73.9 ± 0.9	1.18	0.71 ± 0.03	0.79 ± 0.05	0.68 ± 0.04	CBC	1.16
Hebezu	47.2 ± 1.0	39.9 ± 0.8	1.18	6.30 ± 0.20	6.00 ± 0.19	5.85 ± 0.16	BBB	1.03
Valencia	80.3 ± 0.5	69.2 ± 6.9	1.16	0.84 ± 0.03	0.96 ± 0.05	0.89 ± 0.03	CBC	1.08
Yoshida	72.1 ± 0.7	67.1 ± 1.0	1.08	1.34 ± 0.04	1.35 ± 0.05	1.46 ± 0.06	BBA	0.92
Marsh	90.4 ± 0.5	84.5 ± 1.2	1.07	1.48 ± 0.05	1.60 ± 0.05	1.34 ± 0.05	CBC	1.19
Delta	71.9 ± 0.7	76.1 ± 1.1	0.94	0.81 ± 0.04	1.11 ± 0.07	0.87 ± 0.04	DBD	1.28
Shiranui	88.2 ± 1.1	95.1 ± 1.7	0.93	0.83 ± 0.03	0.88 ± 0.02	1.01 ± 0.02	CBA	0.79
Lemon	52.0 ± 0.7	67.9 ± 0.8	0.77	4.38 ± 0.14	4.34 ± 0.10	4.21 ± 0.08	BBB	1.03

[z]Acid ratios of each portion to the mid section were calculated and classified into different types such as DBD, CBD, DBC, CBC, BBA, CBA and BBB. A: >1.06, B: 1.05~0.95, C: 0.94~0.80, D:<0.79.
[y]Mid-section/stylar end ratio of acid content. [x]Means ± SE. See Fig.1 for details.

Results and Discussion

The transverse diameter, longitudinal length, and acid content in the axial direction of various citrus fruits (Table 1) reveal that the D/L ratio ranged from 1.32 to 1.47 for satsuma mandarin varieties, and from 0.77 to 1.27 for other citrus fruits. All satsuma mandarin varieties with depressed globular shapes showed the greatest acidity in the mid-section (DBD and CBD). 'Miyauchi' iyo, 'Valencia' and 'Delta' oranges, Amakusa and 'Marsh' grapefruits had high acidity in the mid-section (DBC, CBC, and DBD), whereas 'Yoshida' ponkan and 'Shiranui' with oval fruits possessed the highest acidity in the stylar end (BBA and CBA). Lemon and Hebezu, both high-acid citrus species, had similar distribution patterns among the portions (BBB) (Table 1).

Kawano et al. (1993) reported that the mid-section is a reliable portion for a non-destructive evaluation of sugar content with infrared sensors for satsuma mandarin, whereas the stylar end may be a reliable portion for a non-destructive evaluation of acid content of fruit in oval citrus fruits.

The coefficient of correlation (r) between D/L ratio and mid-section/stylar end ratio of acid content (M/S) in different kinds of citrus fruit was 0.76, significant at 0.01 level (Fig. 1). Moreover, the M/S was higher in satsuma mandarin than other cultivars. 'Shiranui' and ponkan are genetically related because 'Shiranui' is a hybrid between Kiyomi (satsuma mandarin × 'Trovita' orange) and ponkan. 'Shiranui' has both lower ratios of D/L and M/S than ponkan.

Fruit shape is closely associated with acid content distribution in fruit, *e.g.* depressed globular for satsuma mandarins, round for oranges and grapefruits, and oval for 'Shiranui,' ponkan and lemon (Iwahori and Kadoya, 1999; Saunt, 2000). Cross-examination of the literature reveals that the D/L ratio ranges from 1.24 to 1.60 (n=21, mean ± SD=1.39 ± 0.10) for satsuma mandarins, 0.88-1.17 (n=13, mean ± SD=1.03 ± 0.08) for oranges, 1.03-1.20 (n=7, mean ± SD=1.11 ± 0.07) for grapefruits, and 1.28 for natsudaidai (Iwahori and Kadoya, 1999; Matsumoto et al. 1997; Saunt, 2000). Likewise, the M/S was 1.27 for 'Valencia' orange, 1.19 for 'Marsh' grapefruit, 1.03 for 'Duncan' grapefruit (Ting, 1969), 1.32 for satsuma mandarin and 1.02 for natsu-

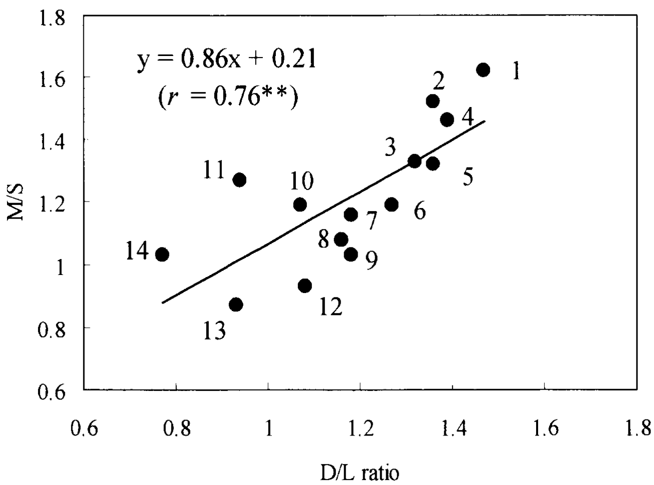

Fig. 1. Correlation between transverse diameter/longitudinal length ratio (D/L ratio) and M/S (See Table 1) in different kinds of citrus fruit. 1:'Kuno'(n=10), 2:'Aoshima'(n=40), 3:'Okitsu'(n=10), 4:'Nankan No. 20'(n=10), 5:'Nichinan No. 1'(n=10), 6:'Miyauchi' iyo (n=30), 7: Amakusa (n=10), 8:'Valencia' orange (n=10), 9: Hebezu (n=10), 10:'Marsh' grapefruit (n=10), 11:'Delta' orange (n=10), 12:'Yoshida' ponkan (n=30), 13:'Shiranui'(n=40) and lemon (n=10).
** Significant at $p<0.01$.

daidai (Shiraishi, 1970). These values fit our regression equation fairly well.

In 'Okitsu' satsuma mandarin fruit, examined between 70 and 230 days after full bloom (DAFB), the M/S peaked at 140 DAFB, while D/L ratio was increasing (data not shown). The M/S was almost identical at harvest (190 DAFB) and after 40 days (230 DAFB) (data not shown). Pulp enlargement continues at late stages in the radial direction in the mid-section for depressed globular fruit and in the axial direction in the stylar end for oval fruit. Since the D/L ratio changes during the ontogeny of citrus fruit, further detailed studies are necessary to determine if there exists such a relationship in the whole process of fruit growth and development. However, 'Delta' orange has a low D/L ratio (0.94), but the acid content is higher in the mid-section than in the stylar end, which indicates that factors other than fruit shapes may be involved in the differential acid distribution. In this regard, acid content in the juice is high for trees subjected to moisture stress (Mukai et al., 1996; Sugai and Torikata, 1976; Yakushiji et al., 1996). Water stress also increased acid content in the central core of the mid-section, but decreased it in the outer portions, compared with the control fruit in satsuma mandarin (Moon and Mizutani, 2002). The organic acid in citrus juice is constituted mostly of citric acid (Daito and Tominaga, 1981). Yen (1987) reported the greater activity of citrate synthase and lesser activity of aconitase in tissues with higher acid levels. The balance between these two enzymes may influence the accumulation of citric acid by affecting its synthesis and degradation. Further studies are required to evaluate the biochemical factors responsible for acid metabolism in different portions of citrus fruits.

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カンキツ果実の形と部位別の酸含量

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摘　要

'日南一号', '興津早生', '南柑 20 号', '久能温州', '青島温州', '宮内' イヨ, 天草, '吉田' ポンカン, '不知火', 'バレンシア' オレンジ, 'デルタ' オレンジ, 'マーシュ' グレープフルーツ, レモンとヘベズを用いて果形と酸含量の分布パターンの関係を調べた. その結果, 果実の横径/縦径の比 (D/L) と中央部/果頂部の酸含量比 (M/S) の間に高い相関が得られた (r=0.76). すなわち扁球形の度合が強まる程, 果実中央部の酸含量が相対的に高くなる傾向がみられた.