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HERITABILITY OF FRUIT QUALITY IN THE PROGENIES OF DAY-NEUTRAL AND SHORT DAY HYBRID STRAWBERRY CULTIVARS

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ABSTRACT

This study was conducted to evaluate the heritability, heterosis, and correlation among firmness, total soluble solid (TSS), and color in the F_1 hybrids between two day-neutral (DN) and six short-day (SD) cultivars. The firmness of DN cultivars and the sweetness of SD cultivars were considered as a criterion in choosing parent cultivars. Parents and eleven F_1 progenies were grown in completely randomized block design. Heritability of TSS, color (*a**: opponent channel between red/magenta and green), and firmness was 0.67, 0.55, and 0.49, respectively. Most of the DN × SD hybrids had higher firmness and TSS than the crossing of SD × SD and DN × DN, respectively. In the DN × SD progenies, all heterosis values of TSS and most of heterosis of firmness were positive and negative, respectively. The genetic advance of TSS was higher than firmness. 'DNKW002' was a better donor for firmness and can be used as female parent in producing DN cultivar with high TSS. Correlation between firmness and TSS was negative, hence the simultaneous selection was recommended. Principle component analysis (PCA) based on characteristics indicated three groups: group of DN parents and hybrids of DN × DN, group of SD parents and SD × SD hybrids, and group of DN × SD and SD × DN hybrids.

Keywords: firmness, total soluble solid, heritability, PCA

INTRODUCTION

Color, texture, fragrance and the balance between sweetness and sourness have been identified as important determinants of overall quality of strawberry fruit (Shamaila, 1992). The ratio of soluble solid content/total acid and pH of fruit was good predictors of sweetness (Guness *et al.*, 2009). The compounds and sensory properties of strawberry fruit such as sugar have been studied (Bordonaba and Terry, 2010). The accumulation of soluble sugars and organic acids depends on stages of fruit development, genotype (Kafkas *et al.*, 2007), and environments (Bordonaba and Terry, 2010).

'Akihime', a Japanese cultivar with high fruit sugar content, has been used as parent in producing new strawberry cultivars in Japan (Kunihisa *et al.* 2003) and also progenitor of 'Seolhyang', 'Keumhyang' and 'Maehyang' in Korea (Je *et al.*, 2007). The major soluble sugar in 'Keumhyang' and 'Maehyang' was sucrose, while 'Seolhyang' and 'Akihime' had higher concentration of fructose and glucose. 'Maehyang' had longer shelf life than 'Seolhyang', 'Keumhyang' and 'Akihime' (Matsumoto *et al.*, 2008). Fruit of 'Maehyang' had higher value of the titration acidity (Kim *et al.*, 2008) and ascorbic acid (Kim *et al.*, 2010) but the hardness, the SSC and hunter value were lower than 'Soogyeong'. Kim *et al.* (2008) noticed that the total yield of 'Seolhyang' was the highest but soluble solid was lower than 'Akihime', 'Maehyang', 'Seonhong', and 'Redpearl'.

'Akihime', 'Seolhyang', 'Maehyang', 'Keumhyang', 'Sachinoka', and 'Soogyeong' are the short day (SD) cultivars with high quality, especially sweetness but their fruit is soft. The SD cultivars had better taste and good aroma. While 'DNKW001' and 'DNKW002' accessions were day-neutral (DN) with high firmness and outstanding for both fresh market and processing, their taste had not been favorably accepted by the panelist due to off-flavor and aroma.

Information about heritability, gene action, and correlation among traits is very important in determination of parent and selection of progenies. Although heritability of soluble solid and sugar

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content has been studied (Ohtsuka *et al*., 2004), but studies regarding the heritability, dominancy effect, and correlation of firmness and sweetness in the crosses between SD and DN cultivars have not been conducted. The regression coefficient of parent-offspring is usually used in cross-fertilizing crops to estimate heritability with full sib progenies that are regressed on the mid parent (Fernandes and Miller, 1985). In this experiment, SD (for sweetness character) cultivars and DN (for firmness character) accession were used as parents and progenies of crossing SD × SD, DN x DN, and SD × DN. The aim was to estimate the heritability of fruit firmness, color, and soluble solids content of berries using parents-offspring regression. Heritability will be useful to decide whether a trait is easily passed through to its progenies to obtain the desired combined trait. Correlation between traits was estimated to predict the selection effect of one trait to others.

MATERIALS AND METHODS

Plant Materials and Crossing

Two Japanese SD cultivars, 'Akihime' ('Kunowase'×'Nyoho') and 'Sachinoka' ('Toyonoka' × 'Aiberry') (Kunihisa *et al*., 2003), four Korean SD cultivars, 'Keumhyang' ('Akihime' × 'Tochiotome'), 'Seolhyang' ('Akihime' × 'Redparl'), 'Maehyang' ('Tochinomine' × 'Akihime'), and 'Soogyeong' (Kim *et al*., 2009), and two DN cultivars, 'DNKW001'and 'DNKW002' were used as parents. The firmness of SD cultivars was lower than DN but conversely, the total soluble solid (TSS) of SD was higher. The daughter plants of parents (Table 1) were grown in 'Plant World' commercial media (Nongwoo Bio, Korea). Automatic nutrient supplier was set up for watering. Complete nutrients solution is added through drip irrigation system with emitters at 30 cm spacing and a flow capacity of 2 L min^{-1} per 30 m tube length, containing (in mg L^{-1}): KNO_3 (286), $Ca(NO_3)2.4H_2O$ (354), $MgSO_4.7H_2O$ (123), KH_2PO_4 (91), NH_4NO_3 (7), H_3BO_3 (3), $MnSO_4.4H_2O$ (2), $CuSO_4.5H_2O$ (0.05), $ZnSO_4.7H_2O$ (0.22), $NaMoO_4.5H_2O$ (0.02) and EDTA-Fe, 20. The pH and EC of the solution was 5.6 and 1.0 dS m^{-1}.

Hybridization was started in April. Flowers were emasculated before corolla opening and enclosed with oil paper. Then two to three days later, the covers of emasculated flowers were opened and the pollen from male parents was scrubbed gently onto the pistil with a fine brush. The cover was replaced with clip to prevent further pollination. Every fertilized flower was marked with female and male parent name in colored lable. One week later, the covers were removed and the fruit developed to ripening. The fully red fruits were harvested and stored in refrigerator for a week then the skin with achene/seed was pealed with blade. The pealed skin-achene from a combination cross was collected in blender and pulsed on and off cycles for 20 second until all seeds separated from flesh and skin. The extracted seeds were washed and put in 1 ppm GA_3 solution for one week in 4 ^oC and then sowed in the commercial media (aforementioned). One month later, seedlings were transplanted singly in plastic pot tray (diameter 3 cm) filled with similar media.

Culturing

The benches were set up, filled with the 'Plant World' commercial media (Nongwoo Bio, Korea) and covered with white plastic mulch in the plastic house of Department of Plant Sciences, Gangneung-Wonju National University, Korea. Alternate planting holes were made with 20 cm distance in row and 25 cm between rows. The seedlings of sixteen progenies and their parents were replanted to the benches.

A complete nutrient solution, containing (in mg L^{-1}): KNO_3 (286), $Ca(NO_3)_2.4H_2O$ (354), $MgSO_4.7H_2O$ (123), KH_2PO_4 (91), NH_4NO_3 (7), H_3BO_3 (3), $MnSO_4.4H_2O$ (2), $CuSO_4.5H_2O$ (0.05), $ZnSO_4.7H_2O$ (0.22), $NaMoO_4.5H_2O$ (0.02) and EDTA-Fe, 20, was supplied through drip irrigation system. Drip irrigation in each bench was set up with pipe (40 m in length, Ø 2.5 in) and emitters at 30 cm spacing and a flow capacity of 2 L min^{-1}. The pH and EC of the solution was 5.6 and 1.0 dS m^{-1}. Temperature was maintained at 7 ^oC/night and 27 ^oC/day. The runner and new crown were removed regularly once in every 1 to 2 weeks. The diseases and insects were controlled using Azoxystrobin, Spiromesifen, and Carbendazim-Diethofencarb. The recommendation dosage was applied in both pesticides.

Data Collection

Fruit firmness was measured as maximum penetration force (N = Newton) on opposite sides of another ± 20 fruit from different plants in each replicate with an automated penetrometer (real time using a material tester

EZ-test, Shimadzu Corporation, Kyoto, Japan) fitted with a 5-mm diameter cylinder, and speed was set to 0.5 mm/sec and 5 mm depth. On each of these fruits, two external (on opposing shoulders) color measurements (Model CR-400 Chromo Meter, Minolta Camera Co., Ltd., Ramsey, NJ) were taken using the L*a*b* color space. The Hunter L*, a*, b* color space is organized in a* cube diffuser. The maximum and minimum for L* were 100 (diffuser) and 0 (black). The a* and b* axis were red and yellow for maximum, and green and blue for minimum, respectively. Soluble solids content (%) was measured in duplicate of each sample berry with a digital Refractometer (Model PR-101, Atago Co., Ltd., Tokyo, Japan).

The collected data (20-50 sample/ genotype) were analyzed to estimate the mid parent heterosis, potence ratio (hp), heritability (parent-offspring regression coefficient, $b_{MP\text{-}F1}$), correlation ($r_{MP\text{-}F1}$) and principle component analysis (PCA). Estimation of these values was done as follows:

Correlation : $r_{MP-F1} = \frac{Cov(MP,F1)}{\sqrt{Var(MP).Var(F1)}}$

(Ohtsuka *et al.,* 2004)

Heritability (h^2): $b_{MP-F1} = \frac{Cov(MP,F1)}{Var(MP)}$

(Ohtsuka *et al.,* 2004; Zalta *et al.,* 2009)

Cov (MP, F_1) is covariance of mid parent and F_1. Var MP or F_1 is variance of mid parent or F_1. Heritability classification as follow: Low (0-20%), Moderate (20 - <50%), High (>50).

$\text{Heterosis} = \frac{(F1-MP)x100\%}{MP}$ (Bakhsh *et al.*, 2007)

The dominance estimates were computed using "potence ratio (hp)" method (Petr and Frey, 1966) and classified in: Over dominant: hp > 1 or < -1; -1<partial dominant <1, no dominant hp=0.

Potence ratio: $hp = \frac{F1-MP}{BP-MP}$

where:

F_1, MP and BP are mean values of F_1, mid parent and better parent, respectively

Parents data were subjected to analysis of variance and Duncan's Multiple Range Test with α = 5%. Principal component analysis (PCA) was used as a tool in grouping DN parents, SD and progenies of crossing based on characters including firmness, total soluble solid and hunter value (a).

RESULTS AND DISCUSSION

The fruit firmness of day-neutral parents (2.81 and 3.5 N/∅ 5 mm) was significantly higher compared with short day cultivars (1.35-2.16 N/∅ 5 mm) (Table 1). In contrary, the total soluble solid and color (L* and a*) of day-neutral parents were significantly lower than those of short day cultivars, specially 'Akihime', 'Maehyang' and 'Sachinoka'. 'Akihime' and 'Maehyang' showed the highest value in color (L* = 35.2 and a* = 35.7) and total soluble solid (11.5 brix), respectively. Day neutral parents had the lowest TSS (5.58 and 7.11 brix) and hunter value of L*(29.4 and 29.5) and a*(29.8 and 30.1).

Generally, the firmness of F_1 hybrids between DN (2.7 N/∅ 5 mm) and DN parent (1.8-2.5 N/∅ 5 mm) was higher compared with F_1 of SD X SD (1.7-2.1 N/∅ 5 mm) (Table 2). The highest firmness was 'DNKW001' X 'DNKW002' (2.7 N/∅ 5 mm) and the lowest was 'Sachinoka' X 'Maehyang' (1.7 N/∅ 5 mm). In firmness, the highest value of heterosis (18%) and potence ratio (5.83) was 'Akihime' X 'Keumhyang', while the lowest was with 'DNKW001' X 'Seolhyang' (-33.2 %) and 'Seolhyang' X 'Maehyang' (-2.89). The firmness of most F_1 progenies was lower than mid parents that were indicated by negative values of the mid parent heterosis (Table 2). For instance, the fruit firmness of 'DNKW001' X 'Maehyang' was 2.1 N/∅5 mm while its mid-parent value was 2.5 N/∅5 mm. Most of the potence ratio value of firmness was also negative.

The fruit of 'Keumhyang' X 'Maehyang' hybrid contained the highest TSS (11.3 brix) among the F_1 hybrids, and the lowest TSS was 5.8 brix with the 'DNKW001' X 'DNKW002' hybrids. The highest value of heterosis and hp for TSS was 30.5% and 3.68 with the 'DNKW001' X 'Soogyeong' hybrids, while the lowest value was -6.3% and -3.61 with the 'Akihime' X 'Keumhyang' and 'Sachinoka' X 'Maehyang' hybrids, respectively. Most of the heterosis and hp in TSS of the F_1 hybrids were positive.

Fruit color of 'Akihime' X 'Keumhyang' conferred the highest hunter values (L*, a*, and b*). The lowest hunter values were 'DNKW001' X 'DNKW002' for L*, 'Akihime' X 'DNKW001' for a* and 'Keumhyang' X 'Maehyang' for b*. 'DNK001' X 'Soogyeong' had the highest heterosis value of L* (6.8%), while both of the 'Akihime' X 'Maehyang' and 'Akihime' X 'DNKW001' hybrids had similar value of L* heterosis (-9.3%) and were the lowest among the F_1 hybrids.

The regression of F_1 progenies and mid parents as an estimate of heritability ($\beta = h^2$) is shown in Figure 1. The regression coefficient of firmness and TSS was 0.498 and 0.678. Regression coefficient of a* was the biggest (0.555) among regression coefficient of hunter value and the smallest was with b* (0.092).

The improvement of firmness of SD and TSS of DN was focused in this experiment. Genetic advance (selection gain) is different from mean progenies produced by selected plants and mean of base population. Genetic advance was focused on the firmness in SD progeny (F_1) as results of crossing with DN as source of fruit firmness, while for TSS was regarding of DN progeny when crossed with SD as a source of high TSS. As shown in Table 3, the highest genetic advance in firmness was 'DNKW001' X 'Sachinoka' (56.9%) and the lowest was 'DNKW002' X 'Seolhyang' (-9.5%). All genetic advance of TSS was positive. 'DNKW002' X 'Seolhyang' had the highest genetic advance (74.7%), while the smallest was at 'Akihime' X 'DNKW001' (23.2).

The correlation between firmness, TSS and color was shown in Table 4. Firmness had significant a negative correlation with TSS (-0.72) and hunter values (-0.403 to -0.433). The high correlation was found between TSS with L* and a* and was between L* with a* and b* as well.

The eigen-values and coefficients of principle components based on firmness, TSS and color of fruit were shown in Table 5. The first two principle components of analysis of firmness, TSS, and color explained 68.8% and 21.8 of total variance or totally 90.6%. Coefficient of firmness and TSS in both principle components was negative and positive in first and second PC, respectively. In Figure 2, first PC was divided by DN and SD cultivars into two different groups, whereas DN group was in the left side of Y axis and SD group was on the opposite position. The progenies of crossing between similar members of group would affiliate in similar group of their parents and crossing progenies of both parent groups.

Table 1. Firmness, total soluble solid (TSS), and color (Hunter value: L*, a*, b*) of parents.

Cultivars	**Firmness (N/∅ 5 mm)**	**TSS (%)**	**L***	**a***	**b***
'Keumhyang'	1.59 b	9.30 bc	29.5 c	32.4 bc	13.0 cd
'Soogyeung'	2.01 ab	9.35 ab	29.2 b	32.5 abc	14.1 bcd
'Maehyang'	2.16 ab	11.55 a	31.5 abc	33.4 ab	13.7 bcd
'Sachinoka'	1.35 b	10.6 ab	33.5 ab	34.5 ab	17.3 a
'DNKW001'	2.81 a	7.11 d	29.5 c	30.1 bc	12.9 cd
'DNKW002'	3.50 a	5.58 d	29.4 bc	29.8 c	12.6 cd
'Seolhyang'	2.05 ab	9.78 ab	33.4 ab	31.9 abc	15.1 abc
'Akihime'	1.69 b	10.18 ab	35.2 a	35.7 a	16.5 ab

Remarks: Means followed by the same letter in a column are not significantly different (P = 0.05) according to Duncan's Multiple Range Test α=5%

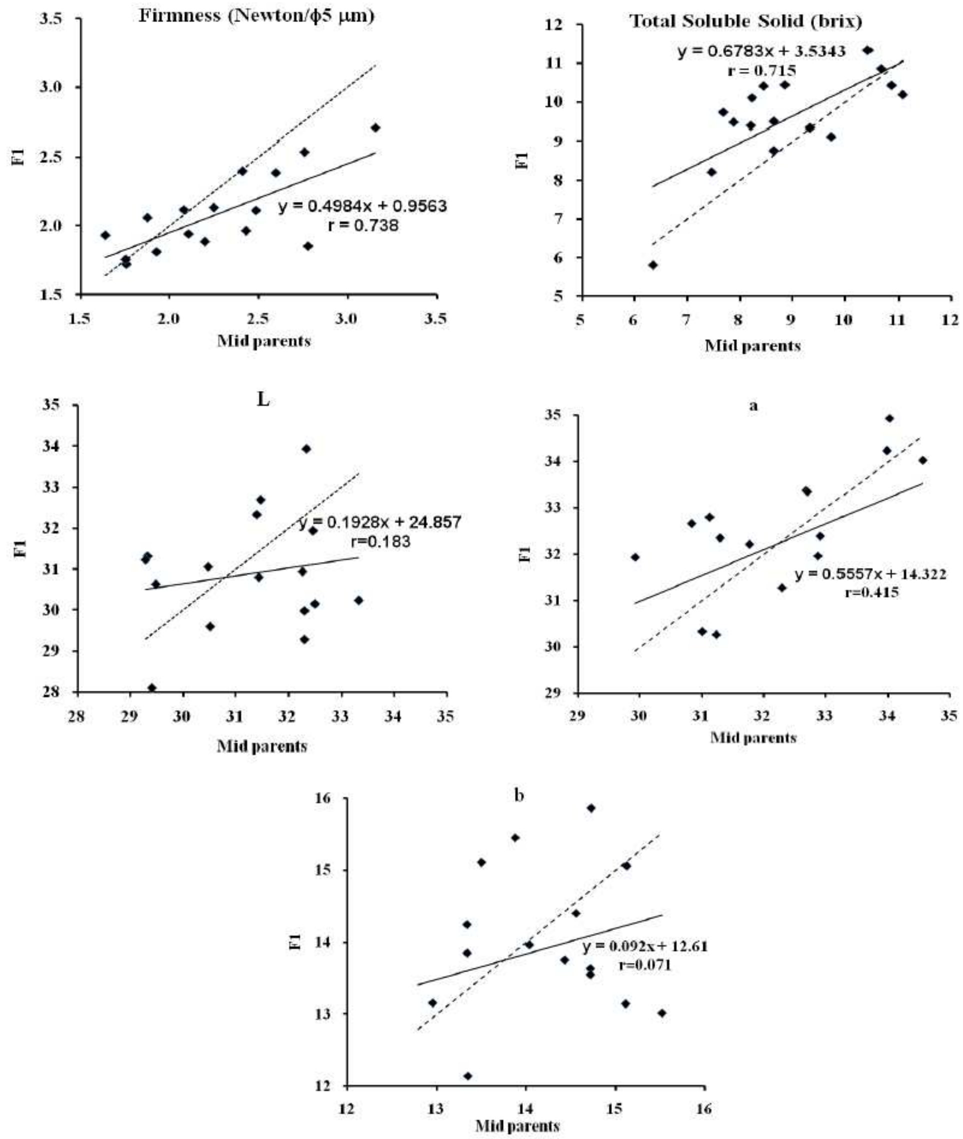


Figure 1. Parents-offspring regression and correlation for firmness, total soluble solid, and color (hunter value : L*, a*, b*). Solid line: estimate regression of data, dotted line: a standar regression with regression coefficient =1; L*, a* and b*: Hunter value; Mid-parents: means of both parent in a crossing combination

Table 2. Heterosis and potence ratio (hp) of firmness, total soluble solid (TSS), color (Hunter value: L*, a*, b*) of F_1

Genotype	Firmness (N/∅ 5mm)			TSS (brix)			L*		a*		b*	
	Mean	Heterosis	hp	Mean	Heterosis	hp	Mean	Heterosis	Mean	Heterosis	Mean	Heterosis
'Akihime' × 'DNKW001'	1.8	0.3	0	8.8	1.4	0.08	29.3	-9.3	27.8	-15.4	13.5	-8.0
'Akihime' × 'Keumhyang'	1.9	18.0	5.83	9.1	-6.3	-1.41	33.9	4.9	34.9	2.7	15.9	7.7
'Akihime' × 'Maehhyang'	1.8	-5.9	-0.48	10.4	-1.1	-0.31	30.2	-9.3	34.0	-1.5	13.1	-13.0
'DNKW001' × 'Akihime'	2.1	-5.0	-0.20	9.5	10	0.56	30.0	-7.2	32.0	-2.8	13.6	-7.4
'DNKW001' × 'Keumhyang'	1.9	-14.1	-0.51	9.4	14.6	1.09	30.6	3.9	30.3	-3.1	13.2	1.5
'DNKW001' × 'Maehyang'	2.1	-14.9	-1.15	9.3	3.7	0.18	31.1	1.9	32.2	1.4	13.8	3.8
'DNKW001' × 'Sachinoka'	2.1	1.9	0.05	10.4	17.9	0.91	32.7	3.9	31.3	-3.1	15.1	-0.4
'DNKW001' × 'DNKW002'	2.7	-14.2	-1.28	5.8	-8.4	-0.69	28.1	-4.5	31.9	6.7	11.8	-7.5
'DNKW001' × 'Seolhyang'	2.0	-19.0	-1.22	10.4	23.3	1.47	30.8	-2.0	30.3	-2.2	14.0	-0.5
'DNKW001' × 'Soogyeong'	2.4	-0.3	-0.02	10.1	30.5	3.68	31.3	6.8	32.4	3.4	15.1	11.9
'Gemhyang' × 'Maehyang'	2.1	9.9	0.65	11.3	12.2	1.53	29.6	-3.0	32.4	-1.6	12.1	-9.1
'Sachinoka' × 'Maehyang'	1.7	-1.9	-0.08	10.2	-5.3	-3.61	30.2	-7.2	34.2	0.8	13.0	-16.1
'DNKW002' × 'Akihime'	2.4	-8.1	-0.23	9.5	20.4	0.7	30.9	-4.1	33.3	2.0	14.4	-1.1
'DNKW002' × 'Seolhyang'	1.9	-33.2	-1.27	9.7	26.9	0.98	32.3	3.0	32.7	5.9	15.4	11.3
'DNKW002' × 'Soogyeong'	2.5	-8.0	-0.29	8.2	17.6	0.87	31.2	6.6	32.8	5.4	14.2	6.8
'Seolhyang' × 'Maehyang'	1.9	-7.7	-2.89	10.9	5.0	0.91	31.9	-1.6	33.4	2.1	13.8	-4.7

Remarks: Number of data was 20-50/ hybrid; Heritability classification: low (0-20%), moderate (20 - <50%), high (>50); Potence ratio: hp > 1 or < -1= over dominant,-1< hp <1= partial dominant, hp=0 : no dominant

Table 3. Genetic advance (ΔG) of firmness in short day cultivars and total soluble solid in day neutral cultivars

Genotype	ΔG Firmness (%)	ΔG Total soluble solid (%)
'Akihime' × 'DNKW001'	4.1	23.2
'DNKW001' × 'Akihime'	26.4	33.7
'DNKW001'× 'Keumhyang'	18.9	32.2
'DNKW001' × 'Maehyang'	-2.2	31.5
'DNKW001' × 'Sachinoka'	56.9	46.9
'DNKW001' × 'Seolhyang'	-4.1	46.5
'DNKW001' × 'Soogyeong'	19.4	42.2
'DNKW002' × 'Akihime'	41.4	70.1
'DNKW002' × 'Seolhyang'	-9.5	74.7
'DNKW002' × 'Soogyeong'	26.3	47.3
'DNKW001'	17.1	36.6
'DNKW002'	19.4	64.1

Remarks: value of 'DNKW001' and 'DNKW002', as day neutral, is the average of genetic advance in hybrid that involved 'DNKW001'or 'DNKW002'

Strawberries undergo rapid softening during ripening and storage, limiting the shelf life of this perishable fruit. Size and shape of fruit, ripening stage (Rasing *et al.*, 2003) and season or different year (Moore, 2001) affect the fruit firmness. The reduction of pectin, a slight decrease of pectin faction covalently bound to cell wall and the decrease of pectin depoly-merization were related to firmness during fruit ripening (Santiago-Domenech *et al.*, 2008).

Firmness of 'Seolhyang' (2.05 N/∅5 mm) was much lower (without statistical test) than the report by Kim *et al.* (2008) about 2.73 N/∅5 mm, and was consistently higher than 'Akihime' (Kim *et al.*, 2008). Firmness of DN cultvars ('DNKW001' and 'DNKW002') was much better than SD cultivars, hence was used as the parents of firmness source. The heterosis and potence ratio value of F_1 fruit firmness was affected apparently by parent firmness. When crossing involved high firmness parents, then the heterosis and potence ratio will be negative.

Partial dominant toward worse parents was allegedly controlling the fruit firmness. In the contrary, positive value of heterosis and potence ratio belonged to the F_1 progenies of 'Akihime' X 'Keumhyang' (overdominance) and 'Keumhyang' X 'Maehyang', but was not in other crossing combinations. The interaction between genes in controlling firmness of strawberry is complicated and depends on genotype combination. It implied that the octoploid plants were not pure lines, as mentioned by Ohtsuka *et al.* (2004).

A heritable trait is most simply an offspring's traits that resemble the parents' corresponding trait (Zalta *et al.*, 2009). The firmness heritability (h^2) estimated by regression of mid parent and F1 showed medium value (h^2 = b = 0.49) that is comparable with the report (0.43) by Mori (2000). Higher heritability estimates of 0.542 and 0.85 were reported by Coman and Popescu (1997) and Ukalska *et al.* (2006), respectively. The difference of heritability value was allegedly caused by different estimating method such as using estimate of variance and covariance of analysis variance method (Ukalska *et al.*, 2006) and different genotype material. Differences in parent heterozygosity also affect heritability magnitude that caused by the dominance effect (Mori 2000). The medium value of firmness heritability implied that improving fruit firmness of progenies was probably medium, although the high firmness parents were used in crossing. By ignoring the negative value of heterosis, however, using 'DNKW001' and 'DNKW002' could improve firmness of the F_1 progenies of 'Akihime', 'Sachinoka' and 'Soogyeong'. The soft strawberry fruit could be improved by crossing with high firmness and with successive process or backcross. Accumulation of advantage genes for firmness could be expected as a highly additive genetic effect (Mori, 2000).

Table 4. Pearson correlation coefficients of firmness, total soluble solid (TSS) and color (hunter value: L*, a*. b*)

	Firmness	L*	a*	b*	TSS
Firmness	1	-0.406*	-0.403*	-0.433*	.725**
L		1	0.565**	0.881**	462*
a*			1	0.473*	441*
b*				1	375
TSS					

Remarks: number with * and ** = significant at 5% and 1%, respectively; N = 24

Table 5. Eigen values and coefficients of principle components

Characters	Prin 1	Prin 2	Prin 3
Firmness	-0.61	0.37	0.69
Total soluble solid	0.61	-0.32	0.71
Color	0.49	0.86	-0.03
Eigen value	2.06	0.65	0.27
Percent of total variance (%)	68.80	21.8	9.40

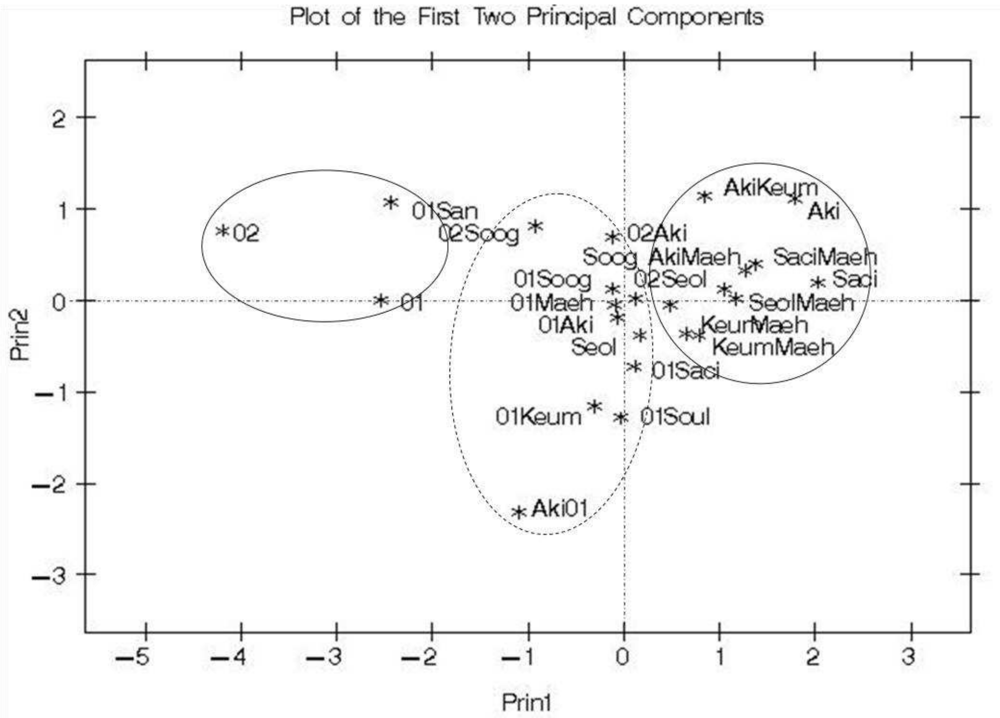
Genetic advance of 'Akihime' and 'DNKW001' and the reciprocal crossing were obviously different. Cytoplasmic effects inherited through mother of DNKW001 were allegedly involved in determination of firmness. Similar case was found by Zebrowska and Dyduch (2009) in morphogenetic capability. The means of genetic advance of crossing that involved DN cultivars were bigger than 'DNKW001' when 'DNKW002' was used as parent.

Total soluble solid (TSS) is the total content of suspended and dissolved solids in water. One of eating quality prediction parameters of fruit is TSS that was positively correlated with total sugars in pineapples (Bartolome *et al*., 1995) and strawberry (Kallio *et al*., 2000). Progenies of 'DNKW001' as female and 'Sachinoka', 'Soogyeong', and 'Seolhyang' as male had TSS more than 10 brix, and contrary TSS of all combinations with 'DNKW002' as female could not achieve 10 brix because the TSS of 'DNKW002' was very low (5.8 brix) and lower than 'DNKW001' (7.11 brix). Selection of plant for discovering DN with high TSS should be carried out between the progenies of 'DNKW001' crossed with 'Sachinoka', 'Seolhyang', or 'Soogyeong'. The variation of total soluble solids was in accordance with total sugar content (Kallio *et al*., 2000). Most of the heterosis and potence ratio of TSS were positive. This condition figured out that heterosis effect and dominance (over or partial) effect were expressed in TSS. Progenies of 'DNKW001' and 'DNKW002' were better than mid parent that differed from fruit firmness. The estimate of TSS heritability (0.67) was higher than sweetness (0.38) found by Ukalska *et al*. (2006). The result indicated that the TSS was not just controlled by partial dominant effect but was additive as well. The average genetic gain in 'DNKW002' progenies was 64.1% higher than in 'DNKW001' (36.6%). It was concluded that 'DNKW002' was better parent for producing high content of soluble solid.

Hunter values were used to characterize the color of fruit in this experiment. Low heritability of hunter values except a* indicated that color of progenies did not depend on high or low hunter values of parents. On the contrary, Ukalska *et al*. (2006) estimated high heritability of skin color. The high heritability of a* is not important in improving 'DNKW001' fruit brightness because the value of a* is from red (high value) to green (low value). Although the heritability of color (L* and b*) is low, the dark color of ripe fruit as one of the weakness of 'DNKW001', however, could be improved through crossing with 'Sachinoka', 'Maehyang' or 'Soogyeong'. Better color of fruit in 'DNKW002' progenies was observed when crossed with 'Akihime', 'Seolhyang' and 'Soogyeong'.

PCA is used to simplify the data structure and still accounts for as much of the total variation in the original data as possible. Cumulative proportion of first and second eigen value reached 0.90 meaning that the first and second principle components constituted 90% of total variance. The most important information was the difference between SD and DN cultivars visualized in the PCA-biplot in principal component 1 (Figure 2). SD cultivars had higher total soluble solid and color (a*) and lower firmness than DN cultivars. The progenies of crossing DN and SD cultivars made a new group that lay down between their parent groups. The progenies of crossing inter SD or DN were included in the same group as their parents.

Correlation between the firmness and total soluble solid (Table 4) was significantly negative. Ukalska *et al*. (2006) also found negative correlation between firmness and fruit sweetness. Correlation between color with total soluble solid and firmness was positive and negative, respectively. The contrary result was found in Ukalska *et al*. (2006) that was negative (-0.06) and positive (0.02) correlation between color skin with sweetness and firmness, respectively. The negative correlation of total soluble solid and firmness is the obstacle in simultaneous improvement of firmness and TSS. Fortunately strawberry is propagated vegetatively, so selection could be focused on individual plant and the selected plant could be vegetatively propagated.



Remarks: The code was abbreviation of cultivar name (example: 01 = DNKW001, Aki = Akihime, Soul =Soulhyang etc)

Figure 2. Plot of principle component analysis of firmness, total soluble solid and color (hunter value a*)

CONCLUSIONS AND SUGGESTIONS

Heritability of firmness and TSS was high and consequently the improvement of both characters are affordable but improvement of TSS is more acceptable in improving TSS of DN cultivars that had higher heritability in firmness. 'DNKW002' was a better donor of firmness and can be used as a mother parent in producing high content of soluble solid of DN cultivars. Simultaneous improvement of firmness and TSS was hampered by negative correlation between firmness and TSS. The genotypes of DN, SD and progenies of crossing between SD and DN were clearly divided into different groups on PCA plotting based on fruit firmness, TSS, and color.

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