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Yield and Relationships among Head Traits in Cabbage as Influenced by Planting Date and Cultivar. II. Processing

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***Abstract.* This is the second of two related reports dealing with the effects of cultivar × environment interactions on cabbage (*Brassica oleracea* L., Capitata Group) crop traits. This study examined planting date and cultivar effects on physical head traits of processing cabbage and compared these findings to those from a similar study of fresh market cabbage. Six cultivars of processing cabbage were planted in May and June–July of 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. Marketable yield for each crop was determined, and measurements were taken of head weight, diameter, density, and volume, and core length, base width, and volume on more than 450 individual heads. Head and core volume and head density were calculated from these direct measures. Year, planting date, and cultivar significantly affected the majority of head traits. May planting led to higher marketable yield and heavier heads with larger diameters than June–July planting. The most variable trait across cultivars was head volume, which was affected by planting date in all cultivars. Differences between processing and fresh market cabbage were found. Average head polar/equatorial diameter values were affected by planting date in the fresh market but not the processing study. In contrast, head density and core volume as a percent of head volume were affected by planting date in the processing but not the fresh market study.**

The final market destination of a crop plays a direct role in its management in the field. For example, harvest is often delayed in processing compared to fresh market cabbage in order to attain the larger head size that is desired in processing markets (Rubatzky and Yamaguchi, 1997). In addition to head size, other parameters, including yield (Strandberg and White, 1979), head density (Howe and Waters, 1994), shape (de Moel and Everaarts, 1990), and core dimensions (Orzolek et al., 2000), change during head formation and maturation (Isenberg et al., 1975) and are affected by cultivar and planting date in both fresh market and processing cabbage. Temperature and daylength differences, as influenced by geographical location, also affect the number of days to harvest and individual head traits (Greenland et al., 2000; Sundstrom and Story, 1984). It is important to explore the effect of market type on relationships among head traits, as well. This is the second of two related studies examining the influence of cultivar and environment on cabbage head traits and their relationships. The objectives of this study were to document cultivar and planting date effects on processing cabbage yield and head weight, diameter, density, and volume, and core length, base width, and volume and to examine relationships among these traits. Findings could also contribute to potential increases in the efficiency of cabbage cultivar development, evaluation, and selection. An additional goal was to describe potential differences between the head traits in this processing cabbage study, and those in the separate, but parallel companion study of fresh market cabbage.

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Materials and Methods

Plot establishment. Acclimated transplants of six commercially important cultivars of processing cabbage (‘Almanac’, ‘Bravo’, ‘Geronimo’, ‘Hinova’, ‘NIZ 95-23’, ‘Score’), having two to four true leaves, were transferred to the field on 11 May 1999, 18 June 1999, 15 May 2000, and 6 July 2000 at the Ohio Agricultural Research and Development Center Vegetable Crops Research Branch in Fremont. The second planting was nearly 3 weeks later in 2000 than in 1999 due to unusually high amounts of rainfall in June and early July of 2000 (2110 mm). Two-row plots, planted with a two-row Holland Finger transplanter (Holland Transplant Co., Holland, Mich.), were arranged in a randomized complete-block design with four (2000) or five (1999) replications per year; each replication contained both planting dates and all cultivars within each planting date. Plots measured 9.2 m long with 76 cm between rows and 46 cm between transplants. Soil type in each year was a Kibbie Fine Sandy Loam (fine-loamy, mixed, mesic Hapludalfs). Preplant fertilizer applications included 72 $kg\cdot ha^{-1}$ P_2O_5 via 0–46–0 and 291 $kg\cdot ha^{-1}$ K_2O via 0–0–60 in Sept.–Oct. 1998 and 1999 and 78 $kg\cdot ha^{-1}$ N via 45–0–0 spread and incorporated ≈2 weeks before planting in 1999 and 2000. Each transplant was provided with ≈150 mL of a dilute nutrient starter solution containing N and P at planting. Standard pest management strategies, based on scouting, thresholds, and application of labeled pesticides, were employed. Plots were irrigated (3.0 mm, 1 July; 12.7 mm, 16 July) in 1999 only.

Harvest and data collection. Plots were examined 2–3 times per week beginning 55 d after transplanting to assess harvest readiness. Specific harvest dates were selected based on estimated days to maturity from the seed source and visual examination of heads. At maturity (69–149 d after planting), all heads were collected from the center 3 m of both rows in each plot. Heads were scored as marketable or unmarketable (small, split, or containing evidence of damage due to physiological disorders, disease, or insect feeding) and weighed as a group. Five marketable heads were then selected at random from the harvested group for further evaluation. Five outer leaves were removed from each head before they were reweighed individually using an electronic scale (FV-60KWP, A and D Co., Tokyo, or CW11-2EO, Ohaus, Pine Brook, N.J.). Heads were then cut in half longitudinally and the core length and base width and head polar and equatorial diameters recorded. The ratio between head polar (P) and equatorial (E) diameter (head p/e) for the 483 heads examined rarely deviated significantly from 1 (Fig. 1A). Overall, 50% of the ratio values were in the range 0.88–1.04 with a mean value of 0.96. Therefore, heads were treated as spheres in calculating head volume using average head diameter values and a standard geometric formula:

$$V = 1.33 \cdot 3.1415927 \cdot r^3$$

where r = average head radius. Head density ($g\cdot cm^{-3}$) was then calculated using weight values taken at harvest and estimated head volume. The core was treated as a cone with core volume calculated as:

$$V = 0.33 \cdot 3.1415927 \cdot r^2 \cdot h$$

with r = 0.5 · base width and h = core length. The percentage of the head volume contained in the core was calculated as the ratio of head to core volume. Thus, for each cultivar, direct measures of head weight, head polar and equatorial diameter, core length and base width were collected on 25 and 20 individual heads per planting date in 1999 and 2000, respectively (a total of more than 200 heads in each year). Values of head density, average diameter, and head and core volume were calculated for each head.

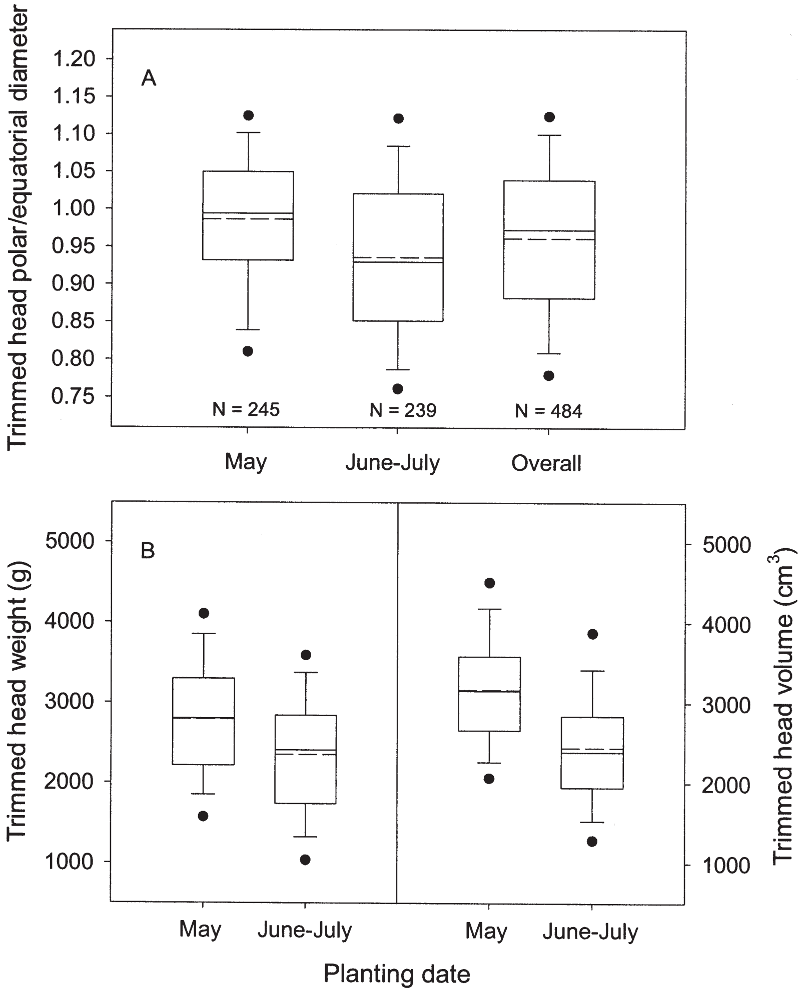

Fig. 1. Planting date effects on head traits of six cultivars of processing cabbage planted in mid-May and mid-June to early July of 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. (**A**) Distribution of trimmed head polar/equatorial diameter values. (**B**) Distribution of trimmed (**left**) head weight and (**right**) volume values. Shown in each panel are the 5th, 10th, 25th, 50th (median value), 75th, 90th, 95th percentiles (bottom-top) and mean (dashed line).

Statistical analysis. Data were subjected to analysis of variance (ANOVA) to test main effects and interactions of year (Y), planting date (PD), and cultivar (C) using Statistical Analysis System version 7 for Windows™ (SAS Institute, Cary, N.C.). Fisher's least significant difference test (α = 0.05) was used to compare treatment (year, planting date) means.

Results

Main effects and interactions on individual head and core traits. Year, planting date and cultivar significantly affected the majority of head and core traits (Table 1). Significant Y × C interactions were recorded for 9 of 10 traits, with head p/e being the exception. The Y × PD interaction was significant for all three core traits (length, base width and volume as percent of head volume). Significant PD × C interactions were also found for core length and base width, as well as for head volume and polar diameter. Core length and base width were affected by all interactions among year, planting date, and cultivar.

When comparing seasonal variation, June–July planting resulted in denser cabbage heads with a slightly larger percent head volume found in the core compared to May planting (Table 2). However, May planting produced higher marketable yields and heavier heads with larger diameters and wider core base widths than June–July planting. Head weight values were distributed over equal but different ranges in May and June–July plantings, as 90% of the May head weights ranged between 1580 and 4100 g, while 90% of the June–July head weights ranged from 1060 to 3580 g (Fig. 1B, left). Head volume was also variable, with 90% of the values from May planting ranging between 2059 and 4497 cm^3 and 90% of the

Table 1. Analysis of variance for the impact of year, planting date, and cultivar on head traits of six cultivars of processing cabbage planted in mid-May and mid-June to early July of 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio.

			Trimmed head							Core		
		Marketable				Diameter					Base	% Head
Source	df	yield	Wt	Vol	Density	Polar (P)	Equatorial (E)	Avg	P/E	Length	width	vol
Year (Y)	1	***	***	***	***	**	***	***	**	***	NS	NS
Planting date (PD)	1	***	***	***	***	***	***	***	NS	NS	***	***
Cultivar (C)	5	*	***	***	***	***	***	***	***	***	***	***
Y × PD	1	NS	NS	NS	NS	NS	NS	NS	NS	**	***	**
Y × C	5	**	***	***	*	***	***	***	NS	***	***	***
PD × C	5	NS	NS	**	NS	**	NS	NS	NS	**	***	NS

NS, *, **, ***Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

Table 2. Influence of year and planting date on yield and head traits of six cultivars of processing cabbage planted at the OARDC Vegetable Crops Research Branch in Fremont, Ohio.

		Marketable	Trimmed head							Core		
		yield	Wt	Vol	Density	Diameter (cm)				Length	Base	% Head
Main effect	N	Mg·ha^{-1})	(g)	(cm^3)	(g·cm^{-3})	Polar (P)	Equatorial (E)	Avg	P/E	(cm)	(cm)	vol
Year												
1999	61	47.2 b[z]	2269 b	2703 b	0.83 b	17.2 b	17.1 b	17.2 b	1.01 a	7.1 b	3.3 a	0.79 a
2000	48	80.9 a	2887 a	2907 a	1.01 a	17.6 a	19.4 a	18.5 a	0.93 b	7.8 a	3.3 a	0.82 a
LSD$_{(0.05)}$		6.4	128	132	0.030	0.30	0.41	0.30	0.05	0.23	0.07	0.08
Planting date												
May	55	73.2 a	2793 a	3159 a	0.88 b	18.2 a	18.6 a	18.4 a	0.99 a	7.4 a	3.4 a	0.74 b
June–July	54	55.0 b	2353 b	2440 b	0.95 a	16.6 b	17.9 b	17.3 b	0.96 a	7.5 a	3.2 b	0.87 a
LSD$_{(0.05)}$		6.4	121	132	0.030	0.27	0.37	0.30	0.05	0.21	0.06	0.07

[z]Numbers in the same column and main effect followed by the same letter are not significantly different according to Fisher's least significant difference test (α = 0.05).

Table 3. Influence of planting date on head traits of six cultivars of processing cabbage planted in 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. Asterisks indicate that planting date had a significant effect on the variable listed within the cultivar according to analysis of variance ($P \leq 0.05$).

			Trimmed head							Core			No. of
					Head	Diameter (cm)					Base	%	10 traits
Cultivar	Planting date	N	Wt (g)	Vol (cm^3)	density (g·cm^{-3})	Polar (P)	Equatorial (E)	Avg	P/E	Length (cm)	width (cm)	Head vol	affected by planting date
Almanac			**	**	**	**	**	**			**	**	8
	May	8	2588	3347	0.770	18.5	17.9	18.2	1.03	6.8	3.2	0.57	
	June–July	8	2079	2458	0.822	16.5	16.7	16.6	1.01	6.6	3.0	0.67	
	LSD$_{(0.05)}$		297	332	0.049	0.70	0.90	0.76	0.031	0.50	0.13	0.061	
Bravo			**	**	**	**		**	**			**	7
	May	8	2807	2768	1.022	17.3	19.3	18.3	0.91	7.9	3.5	0.96	
	June–July	7	2300	2036	1.097	15.6	18.7	17.2	0.85	7.9	3.5	1.31	
	LSD$_{(0.05)}$		259	270	0.070	0.61	0.77	0.63	0.029	0.42	0.15	0.123	
Geronimo			**	**	**	**		**	**		**		7
	May	8	3174	3264	0.973	18.3	20.1	19.2	0.92	7.4	3.6	0.77	
	June–July	8	2551	2283	1.106	16.2	19.4	17.8	0.84	7.1	3.1	0.81	
	LSD$_{(0.05)}$		309	315	0.061	0.69	0.96	0.77	0.030	0.58	0.14	0.076	
Hinova			**	**	**	**		**	**		**		7
	May	8	2688	3221	0.826	18.3	17.7	18.0	1.04	7.5	3.3	0.67	
	June–July	8	2198	2303	0.937	16.3	17.1	16.7	0.96	7.9	2.8	0.88	
	LSD$_{(0.05)}$		276	273	0.061	0.62	0.84	0.67	0.036	0.49	0.11	0.342	
NIZ95-23				**						**		**	3
	May	8	2787	3299	0.827	18.5	18.3	18.4	1.02	7.7	3.2	0.63	
	June–July	8	2658	2987	0.851	18.1	18.4	18.3	1.12	8.5	3.3	0.77	
	LSD$_{(0.05)}$		283	265	0.053	0.64	1.12	0.78	0.288	0.57	0.12	0.061	
Score			**	**		**		**		**			5
	May	8	2713	3042	0.873	18.0	18.2	18.1	0.99	7.3	3.7	0.85	
	June–July	8	2347	2571	0.922	16.8	17.5	17.1	0.97	6.8	3.5	0.87	
	LSD$_{(0.05)}$		340	335	0.056	0.74	0.85	0.76	0.025	0.45	0.14	0.079	
No. of 6 cultivars affected by planting date			5	6	4	5	1	5	3	2	3	3	

June–July planting values within 1372 to 3871 cm^3 (Fig. 1B, right). Core length and head p/e did not vary among seasons (Table 2). Head p/e varied slightly less in the May crop, with 90% of the values ranging from 0.81 to 1.12 (average = 0.99), as compared to the June–July crop, with 90% of values ranging from 0.76 to 1.12 (average = 0.96) (Fig. 1A).

Specific attention was paid to the consistency in the response of selected cultivars and traits to changes in planting date. Certain cultivars and head and core traits were more frequently influenced by planting date than other cultivars and traits. As few as three traits were affected by planting date in one cultivar ('NIZ 95-23'), while five to eight of 10 traits examined were affected by planting date in the remaining five cultivars (Table 3). The most variable trait across cultivars was head volume, which was affected by planting date in all six cultivars, while equatorial diameter was affected in only one cultivar. Head weight and polar and average diameter were also affected by planting date in all but one cultivar ('NIZ 95-23'). Head density was greater following June–July vs. May planting for all cultivars, except 'NIZ 95-23' and 'Score'. The remaining traits (core length, head p/e, core base width, and core volume as percentage of head volume) were affected by planting date in two to three of the six cultivars studied.

Relationships among head and core traits. Several clear relationships were found among selected head and core traits. Head weight and average head diameter were strongly related. Head weight–average diameter plots for May and June–July plantings fit polynomial curves with R^2 values of 0.9 or greater (Fig. 2A). Also, core volume and head volume were related, as the core occupied an average of 0.81% of the head volume (data not shown, but similar trend as in Kleinhenz and Wszelaki, 2003, Fig. 2B). Nonetheless, the percentage of head volume occupied by the core tended to decrease as head volume increased. For example, core volume occupied an average of 0.83% ± 0.26% of head volume in heads 2000–3000 cm^3 (N = 220), yet occupied an average of 0.64% ± 0.18% (N = 40) in heads >4000 cm^3 (Fig. 3). No clear relationship was found between average head diameter and head density. While head density averaged 0.88 and 0.95 g·cm^{-3} in May and June–July plantings, respectively, (Table 2), a view of the entire population revealed that head density (g·cm^{-3}) ranged considerably (0.55–1.45) as head diameter increased (Fig. 2B).

Discussion

The current study reinforced earlier findings that cultivar and planting date can affect cabbage head weight (Fornaris-Rullan et al., 1989), diameter (de Moel and Everaarts, 1990), density (Howe and Waters, 1994), and volume (Kleinhenz and Wszelaki, 2003), and core length, base width, and volume (Orzolek et al., 2000), and marketable yield (Strandberg and White, 1979). Cultivar influenced all 10 head traits measured in processing cabbage, underscoring the influence of genetics on cabbage crop and head traits. Planting date affected the majority of head traits as well, with the exception of head p/e ratio and core length. In contrast, Sundstrom and Story (1984) reported that head length : width ratio and core length were the only traits affected by spring (seeded in January, harvested in the spring) and fall (seeded in August, harvested in the fall) plantings in Louisiana. They also found greater core elongation and rounder heads in the cooler season crop. Given the different latitudes of Ohio and Louisiana, these seemingly contradictory findings could be attributed to differences in temperature and/or light levels (i.e., daylength, solar radiation) (Krishnappa and Amin, 1973; Strandberg and White, 1979), as well as to differences in the cultivars studied.

Head density was greater following June–July vs. May planting and this difference is ascribed to differences in head size : weight ratios between the planting dates. Figure 1B illustrates that head volume values tended to be larger than head weight values following May planting, resulting in densities <1, whereas weight and volume values were nearly identical following June–July planting, generating densities closer to 1 (Table 2). It is interesting to note that differences in head volume may have resulted from a shift in the direction of head growth, as planting date influenced polar diameter to a greater extent than equatorial diameter (Table 3).

Trait stability across planting dates differed among the cultivars studied. Only three of 10 traits of 'NIZ 95-23' were affected by planting date, whereas eight of 10 traits of 'Almanac' were affected by planting date. Such differences among cultivars suggest that some may be best suited for either May or June–July planting in Ohio. Orzolek et al. (2000) reached a similar conclusion in Pennsylvania.

A number of relationships between head traits were apparent, regardless of cultivar and planting date. For example, head weight and diameter displayed a clear polynomial relationship, indicating that as head diameter increased, head weight also increased consistently. Moreover, the average ratio between head polar and equatorial diameters was nearly 1, demonstrating that heads were mostly round and suggesting that reliable estimates of head volume and density are possible. However, other relationships among head and core traits challenged existing assumptions. Anecdotal and, to a lesser extent, scientific (Isenberg et al., 1975) evidence suggests that head density increases with head size. While this appears to be true through head development (Isenberg et al., 1975), we found no apparent relationship between head density and diameter in the numerous mature (market-ready) heads in this study. Small heads were as dense as large heads and density ranged considerably within specific size classes (Fig. 2B). Heads with an average diameter of 20.3 and 21.5 cm ranged in density from 0.571 to 1.376 g·cm^{-3}, as did heads with diameters from 12.0 to 15.6 cm. Also, core volume as a percentage of the head volume was affected by planting date in three cultivars, with the June–July planting producing larger percent core values than the May planting. Interestingly, actual average core volume was greater in the May (22.64 cm^3) vs. the June–July planting (19.83 cm^3). On average, the core accounted for ≈0.81% of the head volume (Fig. 3). But, as head volume increased, the percentage of the volume occupied by the core tended to decrease. In heads with volumes between 2000 and 3000 cm^3, the volume occupied by the core was more than 15% greater than that in heads ranging from 3000 to 4000 cm^3. This shows that core volume generally increased at a slower rate than head volume.

In 1999 and 2000, fresh market and processing cabbage plots were established in parallel but spatially distinct studies at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. Findings from the fresh market study were reported in Kleinhenz and Wszelaki (2003). While most traits were affected by planting date in both the fresh market and processing studies, core length was not affected in either study. Head p/e was not affected by planting date in the processing study, but ratios in the May planting were greater than June–July planting ratios in the fresh market study (Kleinhenz and Wszelaki, 2003). Core volume as a percentage of head volume and head density were unaffected by planting date in the fresh market study, yet core volume and head density following June–July planting were significantly greater than following May planting in the current processing study.

This shift to higher densities in the June–July crop vs. the May crop for the processing, but not fresh market crop, could be due to the greater days to harvest (DTH) for the processing heads. The processing cultivars required 98 to 149 DTH (with the exception of 'Almanac', which required 76 and 69 DTH in 1999 for the May and June–July planting, respectively), while the fresh market cultivars required only 80–124 DTH. The May-planted

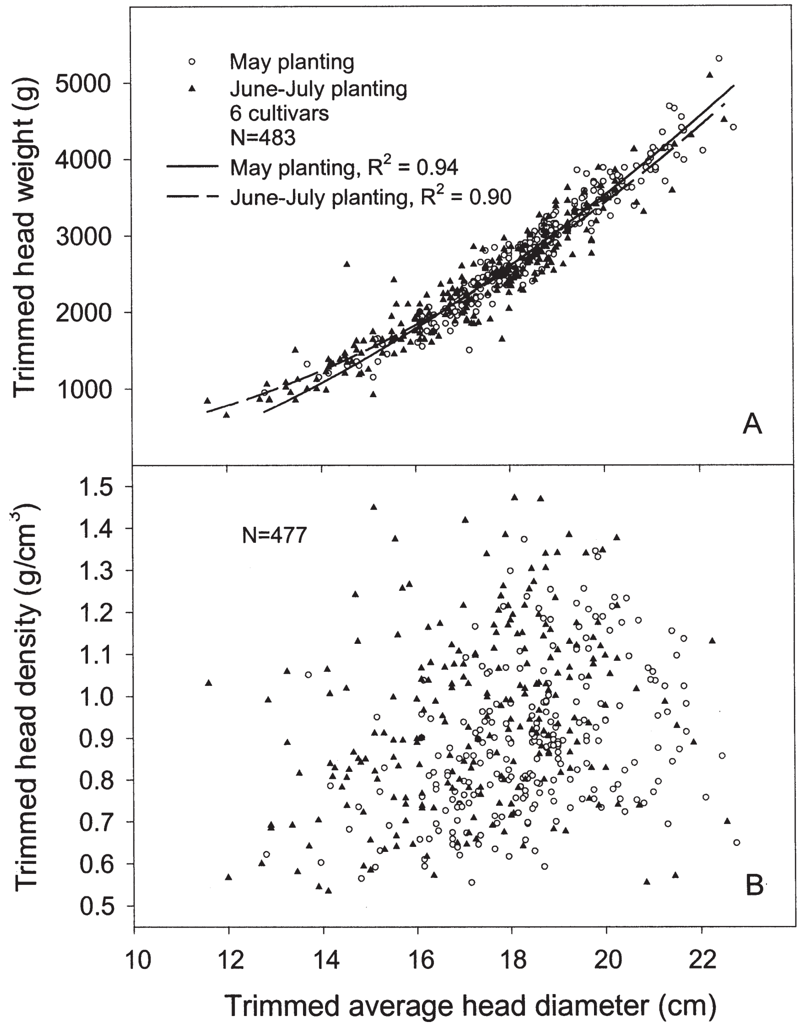

Fig. 2. (**A**) Head weight and (**B**) density in relation to the average diameter of trimmed heads of six cultivars of processing cabbage planted in mid-May and mid-June to early July of 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio. Head density was calculated using estimated head volume and direct measure of individual head weight. Average head diameter values are the mean of the polar and equatorial diameters for each head.

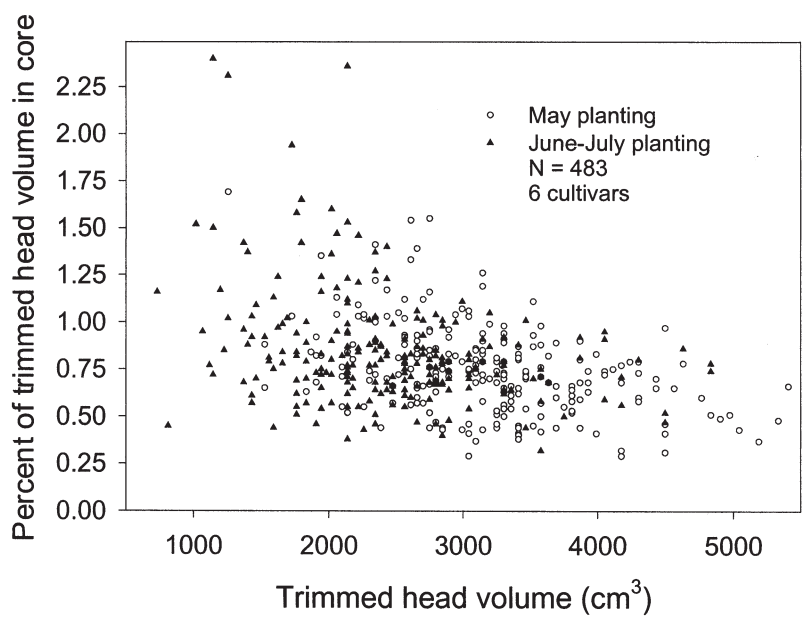

Fig. 3. Percentage of head volume in the core in relation to total head volume for six cultivars of processing cabbage planted in mid-May and mid-June to early July of 1999 and 2000 at the OARDC Vegetable Crops Research Branch in Fremont, Ohio.

processing crops experienced continued high temperatures (>20 °C) during the first 7 d of the last 2 weeks in the field, while fresh market heads had already been harvested. Such high temperatures could cause weight loss that would decrease overall head density. Conversely, the June–July-planted processing crop experienced lower temperatures (<15 °C) soon before harvest, thereby maintaining a higher weight to volume ratio, or overall density. Alternatively, Criddle et al. (1997) determined, by using a respiration-based description of plant growth rate responses to temperature, that cabbage growth will occur, albeit slowly, at temperatures near freezing and at increasing rates up to 16 °C, then at decreasing rates up to a temperature near 21 °C, above which growth is arrested. Therefore, it is possible that the May-planted crops had stopped growing in the field, while the June–July crop continued to accrue mass up to harvest, contributing to their higher densities.

Another interesting difference between fresh market and processing crops is the percentage of head volume occupied by the core. In heads taken from the May planting of fresh market and processing plots, the core occupied an average of 1.14% (Kleinhenz and Wszelaki, 2003) and 0.74% of the head volume, respectively. Yet, actual core volumes averaged 21.06 and 22.64 cm^3 for fresh market and processing cabbage, respectively. This suggests that variation in head size was primarily responsible for differences in the percent head volume occupied by the core, rather than changes in core volume. These differences in head traits between processing and fresh market types were most likely due to the differences in horticultural maturity at harvest. Horticultural maturity is defined as the stage of development when a plant or plant part possesses the prerequisites for utilization by consumers for a particular purpose (Reid, 1992). For some commodities, horticultural maturity is reached at more than one stage of development, depending on the desired use of the product (Reid, 1992). In cabbage, fresh market heads are harvested when they are dense, small to medium in size, and have a good appearance (Greenland et al., 2000). Processing heads often remain in the field longer to attain a larger size, as visual appearance criteria are less important. Here we found a difference in volume of nearly 1000 cm^3, on average, between fresh market and processing cabbage, and a corresponding difference in weight of >1000 g per head. However, even heads of the same size class but of different market type tended to vary in the percent volume occupied by the core. For example, the percent head volume occupied by the core in heads ranging from 3044 to 3753 cm^3 was 0.93% ± 0.19% (Kleinhenz and Wszelaki, 2003) and 0.71% ± 0.19% for fresh market and processing cabbage heads, respectively. Alhough nonsignificant, this points to potential genetic differences for cultivars selected for fresh and processing markets.

With regard to trait stability, fresh market cultivars tended to vary less from May to June planting than processing cultivars did from May to June–July planting. About 30% of the fresh market cultivars were affected by planting date for six of the 10 traits examined, while >60% of the processing cultivars were affected for the majority of traits examined. Also, in the fresh market study, core volume as a percentage of head volume was not affected by planting date in any of the cultivars, while it was affected by planting date in half of the processing cultivars. Overall, core length was the least variable trait across market type. Head volume and polar diameter were the most variable traits across market type.

This study reinforced earlier results that cultivar and planting date strongly influence head and core traits. It also provided strong initial evidence that relationships among important head traits may be affected by market designation. While some differences in traits by market type speak to the genetic variability inherent in selection for that particular market, other differences point to the incongruity in maturity between the market types at harvest and the need for additional study of environmental effects on the growth and development of cabbage in the field. However, regardless of cultivar, planting date, or market type, consistent relationships between head and core traits remain, such as the relationship between head weight and diameter. Such relationships could be used to make quality and harvest evaluations more efficient in the future, by reducing the number of traits that need to be considered in cabbage crop evaluations.

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