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The Use of Weight, Density, Heat Units, and Solar Radiation to Predict the Maturity of Cabbage for Storage[1]

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Abstract. Four cultivars and several breeding lines of storage cabbage were grown by direct seeding and by transplanting over 2 seasons. Weights and densities of heads harvested at successive intervals in conjunction with heat units and available solar radiation yielded estimates of the time to maturity and the mature time interval in the field before splitting is likely to occur. Most cultivars of storage cabbage are ready for harvest when they have attained a density of 0.72–0.80 and a weight of 2.2–3.0 kg which corresponds to accumulation of 1000 to 1050 C heat units (10°C base) and 50,000 to 5000 gm/cal/cm^2 solar radiation units. The interval between maturity and splitting varied from less than 1 week to more than 6 weeks depending upon cultivar and weather conditions.

It is difficult to decide when a given cultivar of storage cabbage is mature enough to harvest because there are no easily discernible changes in the head that indicate this physiological state. Most decisions to harvest are based on general appearance, i.e., the head is exposed and the wrapper leaves are spread, and some degree of firmness is determined by "hand feel". In some years these judgments are difficult, and harvesting may be deferred until some heads have burst, which means that the crop is so mature that more bursting will occur in harvest handling. These criteria, however, plus the known number of days from planting generally determine the decision to harvest. Manual harvesting can often start earlier than machine harvesting, since the cutter can select by using "hand feel" and the field can be cut more than once. This option is lost in the interest of efficiency with machine harvesting. In order to determine whether some objective measurements might be devised to aid or replace these subjective judgments, cabbage was grown during the summers of 1970 and 1973 and subjected to a range of physical measurements in the expectation that 1 or more would correlate with the progression to maturity.

One of our objectives for acquiring these data was to encourage the practice of havesting the storage crop prior to frost as we believe that any frost or freezing may be detrimental to long term storage even when no damage is apparent in the field.

Materials and Methods

In the summer of 1970, 3 cultivars widely used for storage in New York State were grown. They were cv. Harris Resistant Danish (HRD) (3), a hybrid that matures from transplants in approximately 95 days; cv. Great Dane (GD) (4), a hybrid of late mid-season maturity; and cv. Green Winter (GW), an open-pollinated import from Ohlsens Enke, Denmark, with very late maturity in Central NY. The cabbage was direct seeded at Freeville on 'river bottom' silt loam soil on May 28 and June 16. Each plot consisted of 9 rows of 100 plants replicated 4 times for each date.

For the maturity study, 3 heads were harvested at random from each of the 4 replications. The first planting was harvested at 4 intervals, September 9 and 23, and October 2 and 12. The second planting was harvested September 23, October 2 and 12.

The measurements observed for each head were wt, length of the longitudinal axis, the horizontal axis, the circumference, and the volume from which density was calculated. To measure volume, a large battery jar was fitted with a side-arm graduated in 0.1 ml increments. Calculation by displacement curve indicated that 0.1 ml was equivalent to 125 ml volume. In practice the side-arm measurement was read to the nearest 0.05 ml graduation. Since the majority of the heads near maturity were 2000 to 3000 ml, the reading error was 1.5 to 1.0% at most. For volume measurement, each head, trimmed of wrapper leaves, was placed in a plastic bag and enclosed air was removed by aspirator vacuum so that the plastic bag adhered tightly to the head. The head was immersed in the battery jar, and while under vacuum, the displacement noted on the side arm.

Weather data were obtained from the official weather station in Ithaca in 1970 and from a newly erected weather station at Freeville Farm in 1973. The mean daily data from these stations are in very close agreement since the distance between them is 7 miles.

In 1973 the experiment was repeated in modified form based on the results of the 1970 season. The cultivars tested included 'HRD', 'GW', 'Excel' (Joseph Harris Seed Company), and a selection from cv. 'Green Winter' (GWS), plus some breeding lines, F2B/3731, 2B/3991, BD4561, F13B/3881 for which we had no information on probable maturity dates. The 'GW' and 'HRD' were direct seeded on two dates, May 29 and June 5, in plots of 0.25 hectares, the others were sown in Speedling (R)[3] flats on April 25, and transplanted to the field on June 5. Each of the transplant plots was a row approximately 25 m long, depending upon the amount of seed available. Ten adjacent heads were harvested for each sample beginning when the cultivar appeared to be approaching maturity

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by the usual visual criteria. Cutting began for the transplants on August 7 and on September 12 for seeded cabbage and was continued at intervals until October 31. The measurements were wt, volume, and calculated density.

Results and Discussion

Upon inspection of the 1970 data, it was evident that wt, density, or a combination of these data probably were more meaningful over a broader range of cultivars and conditions than were measurements of the longitudinal axis, horizontal axis or circumference in determining maturity. Some of the latter 3 measurements were significantly different for harvest dates, but were difficult to use and not of sufficient practical value to recommend them in a regular evaluation procedure. For these reasons, these data are not included in this report.

Inspection of the wt and density data generally reaffirmed the observed genetic differences characteristic of each cultivar when grown under identical conditions of heat accumulation, moisture and solar radiation.

The cv. HRD seeded on May 28, 1970 attained a wt of 1.9 kg in 104 days, which is the upper limit generally described for this cultivar, 1.8 kg (3). At this time the density was 0.73. This cultivar continued to increase in wt in succeeding harvests, but attained no significant increases in density (Table 1). The last harvest on October 12 had many burst heads, although the increase in density was small. When 'HRD' was planted on June 16, it attained characteristic wt in 99 days, but was lower in density at that time than in subsequent harvests. However, this 'HRD' planting did not increase wt, remaining within the wt range characteristic for it, 1.4 to 1.8 kg, although the density increased to 0.77 (Table 2). At 118 days from seeding 'HRD' in both plantings were approximately 0.76 in density with the earlier planting about 500 g heavier. This was considered a suitable state of maturity for good yield and solidity for this cultivar.

The cv. GD seeded on May 28 had good wt gain (Table 1) but the data were not significantly different due to large wt differences within each harvest date. The early planting attained its maximum density, 0.73, in 118 days, but was less dense than 'HRD' grown under the same conditions. In June 16 planting (Table 2), this cultivar was even less dense, attaining its maximum density of 0.69 in 99 days and maximum wt in 108 days. However, the 118 day data for both plantings appeared to be optimum for determining maturity of this cultivar. As grown in this test during this season, the cv. GD was not uniform, although this result was contrary to cultivar description (4).

The late-maturing cv. GW seeded on May 28 (Table 1) attained its maximum wt in 127 days and its maximum density in 137 days. The most suitable criteria for harvesting this cultivar appeared to be a wt of 2.9 kg and a density of 0.75. The June 16 (Table 2) planting had not reached this set of criteria when cut on October 12 and was considered to be immature.

The degree-day (1, 2) accumulations (Table 3) and solar radiation accumulations were slightly higher for the earlier planting of May 28 with the difference in solar radiation being about 10%. However, these differences are not enough to account for the wt differences noted between the 2 plantings when each was grown to 118 days. At 118 days the earlier planting had had less rainfall than had the later planting, which may have influenced density more than was expected.

In summation for 1970, it appeared that; 1) the most rapid increase in both wt gain and density of all cultivars occurred during the period of 100 to 120 days after seeding, and 2) a wt of 2.0–2.5 and a density of 0.75 were characteristic of mature storage cabbage.

In 1973, cv. Excel was mature in 72 to 77 days after transplanting with an average density of 0.78 and a wt of approximately 2 kg (Table

Table 1. Weights and densities of 3 cabbage cultivars after different growth periods from planting on May 28, 1970.

Cultivar	Wt and density[z]	Harvest date and growth period			
		Sept. 9 104 days	Sept. 23 118 days	Oct. 2 127 days	Oct. 12 137 days
HRD	kg/head[z]	1.9c[y]	2.2bc	2.6ab	2.9a
	density	0.73	0.76	0.77	0.78
GD	kg/head	2.4	2.8	3.1	3.3
	density	0.63b	0.73a	0.67ab	0.72a
GW	kg/head	1.6b	2.5a	2.9a	2.7a
	density	0.64c	0.70b	0.74ab	0.76a

[z] Means of 12 heads.
[y] Mean separation, within cultivars, by Duncan's multiple range test, at 5%; means without letters did not differ from one another.

Table 2. Head wt and densities of 3 cabbage cultivars after different growth periods from planting on June 16, 1970.

Cultivar	Wt and density[z]	Harvest date and growth periods		
		Sept. 23 99 days	Oct. 2 108 days	Oct. 12 118 days
HRD	kg/head	1.9	1.6	1.7
	density	0.70b[y]	0.72ab	0.77a
GD	kg/head	1.9b	2.9a	2.9a
	density	0.69	0.67	0.67
GW	kg/head	1.1b	1.7a	1.6ab
	density	0.59	0.60	0.68

[z] Mean of 12 heads.
[y] Mean separation, with cultivars, by Duncan's multiple range test, at 5%; means without letters did not differ from one another.

Table 3. Cumulative degree days, precipitation and solar radiation during different growing periods used for cabbage harvest study in 1970.

Growing period		Degree days 10°C base recorded at 7.6 cm	Precipitation cm	Solar radiation accumulation gm/cal/cm²
5/28–9/9	104 days	892	30.1	55371
5/28–9/23	118 days	983	33.9	60366
5/28–10/2	127 days	1051	37.7	62815
5/28–10/12	137 days	1092	42.4	65669
6/16–9/23	99 days	888	33.1	48598
6/16–10/2	108 days	919	36.9	51047
6/16–10/12	118 days	960	41.6	53901

Table 4. Head wt and density of cabbage breeding lines compared with those of 'Excel' after different growth periods from transplanting June 5, 1973.

Cultivar	Wt and density	Harvest date and growth period				
		Aug. 7 63 days	Aug. 13 69 days	Aug. 16 72 days	Aug. 21 77 days	Aug. 28 84 days
Excel	kg/head[z]	0.91b[y]	—	2.0a	2.1a	2.4a
	density	0.65b	—	0.75a	0.82a	0.80a
F2B/3731[x]	kg/head	1.7b	—	2.3a	2.7a	2.8a
	density	0.60b	—	0.73a	0.76a	0.77a
F13B/3881[w]	kg/head	2.2c	2.7bc	2.7bc	3.7a	—
	density	0.62c	0.67bc	0.70ab	0.74a	—
2B/3991[v]	kg/head	1.1c	—	1.7b	3.1a	—
	density	0.67b	—	0.76a	0.83a	—
BD/4561	kg/head	1.1b	—	1.6b	2.2a	—
	density	0.66b	—	0.76a	0.81a	—
GW	kg/head	1.7c	—	2.3b	2.6ab	3.1a
Selection	density	0.69c	—	0.75b	0.81a	0.76b

[z] Mean of 10 heads.
[y] Mean separation, within cultivars, by Duncan's multiple range test, at 5%; means without letters did not differ from one another.
[x] F2B/3731, 2 heads of 8/21 harvest were cracked and 8 heads of 8/28 harvest.
[w] F13B/3881, 4 heads of 8/13 harvest were carcked, 5 heads of the 8/16 and 8 heads of the 8/21.
[v] 2B/3991, 4 heads of 8/21 harvest were cracked.

4). An additional 7 days in the field made no significant improvement in density or wt of 'Excel' in this planting. This cultivar has been described as a late-midseason type and its performance can be used as a standard for comparison for breeding lines whose maturity characteristics are unknown.

The data on the numbered breeding lines indicated that only one, BD/4561, had the characteristics highly desirable in fresh market storage cabbage, i.e., low wt and high density without cracking (Table 4). However, this test was performed primarily to determine the usefulness of the testing method and not necessarily the performance of the individual breeding lines. How these lines would perform if grown later in the season, or from direct seeding could be quite different.

'GWS' matured early, possibly 10 days less than normal. This was indicative of the generally early maturity of all cabbage in this test. However, the wt/density test indicated early maturity (Table 4).

'GW', field seeded on May 29 reached a density of 0.73 in 107 days and did not increase in density over the next 2 weeks (Table 5). The wt doubled during the same period and it was judged to be ready for harvest at 120 days when its wt averaged 3.5 kg. From this point, there were no significant gains in either wt or density up to 156 days from seeding.

'GW' seeded on June 5 (Table 6) attained a density of 0.73 in 107 days at 2.8 kg. There was a large increase in both density and wt between the 99th and the 107th day, but there were no significant increases in either wt or density after the 107th day until the final harvest at 148 days. This planting was judged to be mature at 122 days when the wt was approximately 3.0 kg.

The cv. HRD seeded on May 29 (Table 5) attained a density of 0.82 in 107 days from seeding with a wt of 1.8 kg, well within normal performance for this cultivar. At 115 days the wt had increased to 2.2 kg with no significant change in density, and the planting was in optimum condition for harvest. Some small heads were left in the field and inspected again on October 31, 156 days from seeding. These heads had matured to a minimum wt characteristic of this cultivar, 1.4 kg, but had attained a density of 0.9, the most dense heads of cabbage we have measured.

'HRD', seeded on June 5 (Table 6) attained maturity in 99 days with a mean wt of 2.5 kg (good for this cultivar) and a density of 0.79. At 107 days the wt was 3.3 kg but the increase was not significant. However, at this date, 'HRD' was considered to be of good harvest maturity.

The cv. GW seeded on May 29, 1973 required 1039 heat units and 53374 gm/cal/cm^2 of solar radiation to attain maturity at 120 days (Table 7). The 1970 planting required 127 days to reach the same degree of maturity with 1051 heat units and 62815 gm/cal/cm^2 of solar radiation required. The difference of 7 days and the additional solar radiation needed were likely due to the fact that the 1970 crop was grown on rather heavy 'river bottom' land, while the 1973 crop was grown on well-drained gravelly loam at higher elevation and with better air drainage.

Table 5. Head wt and density of 2 cabbage cultivars at 4 harvest dates after planting on May 29, 1973.

Cultivar	Wt and densities	Harvest date and growth period			
		Sept. 12 107 days	Sept. 20 115 days	Sept. 25 120 days	Oct. 31 156 days
GW	kg/head[z]	1.6c[y]	2.6b	3.5a	3.0ab
	density	0.73	0.73	0.72	0.78
HRD[x]	kg/head	1.8ab	2.2a	—	1.4b
	density	0.82ab	0.79b	—	0.90a

[z] Mean of 10 heads.
[y] Mean separation, within cultivars, by Duncan's mulitple range test, at 5%; means without letters did not differ from one another.
[x] Harris Resistant Danish. The 10/31 harvest was from small sized plants left from previous harvests, but in good condition on 10/31. These were included because of the high density.

Table 6. Head wt and density of 2 cabbage cultivars on 4 harvest dates after planting, June 5, 1973.

Cultivar	Wt and densities	Harvest date and growth period			
		Sept. 12 99 days	Sept. 20 107 days	Oct. 5 122 days	Oct. 31 148 days
GW	kg/head[z]	2.1b[y]	2.8a	3.2a	3.3a
	density	0.64b	0.73a	0.70a	0.72a
HRD[x]	kg/head	2.5	3.3	—	2.8
	density	0.79	0.75	—	0.80

[z] Mean of 10 heads.
[y] Mean separation, within cultivars, by Duncan's multiple range test, at 5%; means without letters did not differ from one another.
[x] Harris Resistant Danish. The 10/31 harvest was from small sized plants left from previous harvests, but in good condition on 10/31.

Table 7. Cumulative degree days, precipitation and solar radiation during different growing periods used for cabbage harvest study in 1973.

Growing period		Degree days 10°C base recorded at 7.6 cm	Precip-itation cm	Solar radiation accumulation gm/cal/cm^2
6/5–8/7	63 days	618	18.8	33310
6/5–8/13	69 days	680	19.5	35798
6/5–8/16	72 days	705	19.7	36856
6/5–8/20	77 days	744	19.9	38029
6/5–8/28	84 days	831	20.1	41028
6/5–10/31	148 days	1005.8	33.8	59501
5/29–8/12	75 days	733	20.2	38149
5/29–9/12	107 days	1022	23.6	50108
5/29–9/20	115 days	1034	27.0	52273
5/29–9/25	120 days	1039	28.5	53374
5/29–10/31	156 days	1059	33.0	62620
6/5–9/12	99 days	976	26.9	47372
6/5–9/20	107 days	991	29.6	49537
6/5–10/5	122 days	1054	31.5	53118
6/5–10/31	148 days	1221	34.8	59501

The 'GW' seeded on June 5, 1973 required 122 days to maturity at which point it had accumulated 1054 heat units and 53118 gm/cal/cm^2 of solar radiation, almost identical to the May 29 seeding.

The June 5th, 1973, 'HRD' planting required only 107 days to reach maturity with 991 heat units and 49537 gm/cal/cm^2 accumulated. When compared to the May 29 seeding that required 115 days, it was noted that the daily average for both heat units, 9.3, and solar radiation, 462, were slightly higher for the later planting than for the earlier one with 9.0 and 454 respectively. Also the later planting had approximately 2.5 cm more rain during the growing period. This combination of environmental factors may have caused the more rapid growth of the second planting. Harvest wt of 3.3 kg was far larger than is normally expected for this cultivar; i.e., 1.4 to 1.8 kg (3). The system of testing however, warned us of the rapidly approaching maturity and also guided our decision when to harvest. We were able to obtain a heavy yield with no frost damage, which we think is highly desirable for cabbage intended for CA storage.

From 2 seasons' data it appeared that the long season cv. Green Winter will mature at a weight of approximately 3 kg and a density of 0.71 to 0.73 under our conditions. To reach this state requires approximately 1030 to 1050 heat units with a solar radiation accumulation of 53000 gm/cal/cm^2 units. The 'HRD' early storage cultivar appeared to mature at a wt of 2.2 to 3.0 kg with a density of 0.75 to 0.80. This cultivar required approximately 1000 to 1050 heat units and solar radiation of 51000 ± 1000 gm/cal/cm^2.

When both transplanted and seeded plantings are considered, a general rule for all cultivars and breeding lines tested appeared to be

that maturity in Danish cabbage occurred at 0.72 to 0.80 density and 2.2 to 3.0 kg.

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