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Improving the Prediction of Processing Pea Maturity Based on the Growing-degree Day Approach

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Abstract. **The heat-unit system, involving the sum of daily mean temperatures above a given base temperature, is used with processing pea (*Pisum sativum* L.) to predict relative maturity during the growing season and to schedule planting dates based on average temperature data. The Quebec pea processing industry uses a base temperature of 5 °C to compute growing-degree days (GDD) between sowing and maturity. This study was initiated to verify if the current model, which uses a base temperature of 5 °C, can be improved to predict maturity in Quebec. Four pea cultivars, 'Bolero', 'Rally', 'Flair', and 'Kriter', were grown between 1985 and 1997 on an experimental farm in Quebec. For all cultivars, when using a limited number of years, a base temperature between 0.0 and 0.8 °C reduced the coefficient of variation (CV) as compared with 5.0 °C, indicating that the base temperature used commercially is probably not the most appropriate for Quebec climatic conditions. The division of the developmental period into different stages (sowing until emergence, emergence until flowering, and flowering until maturity) was also investigated for some years. Use of base temperatures specific for each crop phase did not improve the prediction of maturity when compared with the use of an overall base temperature. All years for a given cultivar were then used to determine the base temperature with the lowest CV for predicting the time from sowing to maturity. A base temperature from 0 to 5 °C was generally adequate for all cultivars, and a common base temperature of 3.0 °C was selected for all cultivars. For the years and cultivars used in this study, the computation of GDD with a base temperature of 3 °C gave an overall prediction of maturity of 2.0, 2.4, 2.2, and 2.5 days based on the average of the absolute values of the differences for the cultivars Bolero, Rally, Flair, and Kriter, respectively.**

The heat-unit system, involving the sum of daily mean temperatures above a given base temperature, is used with processing pea to predict relative maturity during the growing season and to schedule planting dates based on average temperature data. A base temperature of 4.4 °C was often reported to be the most satisfactory for green peas (Borchers, 1981; Boswell, 1927; Katz, 1952; Rubatzky and Yamaguchi, 1997; Swiader et al., 1992). However, the base temperature varies depending on the heat requirement of pea types. A base temperature of 6.6 °C was selected for southern pea (Hoover, 1955), while 0 °C was selected for cold-tolerant winter pea (Ney and Turc, 1993).

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Heat-unit systems often predict the developmental time from seeding to crop maturity. However, the idea of using checkpoints during pea crop development is not new (Boswell, 1929). Katz (1952) used dates of seedling emergence, blooming, and pod setting. Hoover (1955) focused on the period between seedling emergence and flowering because it covered most of the time for the crop to mature and reduced the adverse effect caused by water stress during germination. Ney and Turc (1993) used three stages: flowering, initiation of seed filling, and physiological maturity. Etévé and Derieux (1982) proposed that the base temperature of the heat-unit system changes with developmental stages of cold-tolerant winter peas: soil temperature of 1 °C for seedling emergence and air temperature of 3 °C for flower initiation.

The optimal temperature for a pea crop will vary with its growth stage. Best germination occurs between 25 and 30 °C, with a minimum at 10 °C and a maximum at 35 °C (Hoover, 1955; Lorenz and Maynard, 1988). After germination, the optimal growth temperature ranges between 10 and 19 °C (Chaux and Foury, 1994; Lorenz and Maynard, 1988; Rubatzky and Yamaguchi, 1997; Swiader et al., 1992). Depending on varietal and environmental conditions, a pea crop takes 56–75 d to reach maturity after planting (Lorenz and Maynard, 1988). Minimum temperature for growth is ≈4 to 7 °C, with lower temperature causing primordia leaf destruction at the flower initiation stage and serious damage to flower buds after flowering (Chaux and Foury, 1994; Lorenz and Maynard, 1988; Swiader et al., 1992). A daily mean of 20 °C was found to be near the critical point, with higher temperatures having adverse effects (Boswell, 1929; Ney et al., 1993). The period of 5–11 d after full bloom was reported as particularly sensitive to high temperature, with 27 °C being a critical level above which yields were reduced (Karr et al., 1959; Lambert and Linck, 1958; Nonnecke et al., 1971).

The Quebec pea processing industry uses a base temperature of 5 °C to compute growing-degree days (GDD) between sowing and maturity. The objective of this study was to verify if the current model, which uses a base temperature of 5 °C, can be improved to predict pea maturity in Quebec. Furthermore, the division of the developmental period into different stages (sowing until emergence, emergence until flowering, flowering until maturity) was also investigated.

Materials and Methods

Field layout. Four pea cultivars were grown between 1985 and 1997 on loamy or clayey soils at the experimental farm of the Horticultural Research and Development Centre of Agr. and Agri-Food Can. located at L'Acadie, 20 km southeast of Montreal, Que. (lat. 45°19′N, long. 73º21′W). Since 1985, continuous trials have provided information on varieties. The cultivars included 'Bolero' (large sieve size), 'Rally' and 'Flair' (medium sieve size), and 'Kriter' (small sieve size), supplied by Asgrow Seed Co. (London, Ont., Can.) (Table 1).

Sowing occurred between the second week of May and the first week of June depending on the year (Table 2). Peas were sown using a John Deere 9350 seeder (Moline, Ill.) at a rate of 25–30 seeds per meter and a depth of ≈2.5 cm (3.5–4.5 cm under dry conditions). Each plot measured 15 × 1.68 m and included 12 rows spaced at 15 cm. The field layout was arranged in a randomized complete-block design with four blocks. Nitrogen was applied at a rate of 15–30 kg·ha^{-1} depending on year and phosphorus and potassium according to

Table 1. Information on processing pea cultivars.[z]

Cultivar	Node no. first bloom	No. days for processing	Plant ht (cm)	Pod length (cm)	Pod width (cm)	No. seeds/ pod	Seed wt (g/100 seeds)
Bolero	15	73	67	8	13	8	18
Rally	11	70	35	6	11	8	17
Flair	11	69	45	7	11	8	15
Kriter	11	69	40	6	12	8	14

[z]Source: Plant variety protection office (Beltsville, Md.).

soil tests. Weed control was performed using a preemergence herbicide and then manually when required. Irrigation was applied immediately after seeding, when needed, and thereafter supplemental irrigation was applied only during dry periods.

Plant emergence was defined as the time when an average of 80% of the seeds of all cultivars were at the cotyledon stage, and flowering time when 10% of the plants showed at least one flower. This latter stage was used to characterize the beginning of flowering.

In the center of each plot, 10 m of 12 rows were harvested by hand. Maturity was determined according to tenderness using a tenderometer (Food Machinery Corp., Hoopeston, Ill.) from 1985 to 1992, and an electronic tenderometer (Food Tech. Corp., Rockland, Md.) from 1993 to 1997. Tenderness criteria varied according to pea size: 100 for the small sieve size, 105 for the medium, and 110 for the large. Daily minimum (Tmin) and maximum (Tmax) temperatures at a height of 1.2 m were recorded from a weather station located on the experimental farm at 400–500 m from the plots. Average temperatures for each growing period are given in Fig. 1.

Analysis procedure. The cumulative GDD required to reach emergence, flowering, and

Table 2. Sowing, emergence (Emerg.), flowering (Flower.), and maturity dates for four pea cultivars from 1985 to 1997 at L'Acadie, Que., Canada.

			Cultivar							
All cultivars			Bolero		Rally		Flair		Kriter	
Year	Sowing	Emerg.	Flower.	Maturity	Flower.	Maturity	Flower.	Maturity	Flower.	Maturity
1985	14 May	---	---	---	25 June	19 July	---	---	25 June	15 July
1986	13 May	---	1 July	21 July	25 June	21 July	---	---	25 June	18 July
1988	1 June	---	---	---	10 July	25 July	---	---	8 July	24 July
1989	18 May	---	26 June	15 July	23 June	11 July	22 June	11 July	23 June	8 July
1990	9 May	---	27 June	19 July	21 June	14 July	21 June	14 July	21 June	13 July
1991	13 May	---	26 June	10 July	19 June	7 July	---	---	18 June	4 July
1992	19 May	27 May	30 June	22 July	25 June	17 July	25 June	15 July	25 June	15 July
1993	12 May	25 May	2 July	15 July	27 June	12 July	28 June	11 July	25 June	10 July
1994	21 May	30 May	2 July	18 July	26 June	13 July	27 June	13 July	26 June	11 July
1995	10 May	20 May	22 June	8 July	19 June	4 July	18 June	3 July	18 June	1 July
1996	9 May	20 May	23 June	16 July	16 June	11 July	26 June	14 July	---	---
1997	22 May	2 June	1 July	18 July	26 June	16 July	---	---	---	---

Table 3. Base temperatures and corresponding coefficients of variation (CV) values for estimating developmental time (growing-degree days) from sowing to maturity of four pea cultivars using four approaches integrating sowing, emergence, flowering, and maturity times.

Cultivar	No. years	Method	Base temp (°C)[z]	CV (%)
Bolero	6	Sowing–maturity	5.0	4.18
	6	Sowing–maturity	0.8	3.62
	6	Sowing–flowering, flowering–maturity	0.0, 10.0	4.10
	6	Sowing–emergence, emergence–flowering, flowering–maturity	5.1, 0.0, 10.0	3.67
Rally	6	Sowing–maturity	5.0	4.48
	6	Sowing–maturity	0.0	3.60
	6	Sowing–flowering, flowering–maturity	3.3, 7.7	4.33
	6	Sowing–emergence, emergence–flowering, flowering–maturity	5.1, 1.5, 7.7	3.77
Flair	5	Sowing–maturity	5.0	4.18
	5	Sowing–maturity	0.0	3.62
	5	Sowing–flowering, flowering–maturity	2.9, 5.4	4.13
	5	Sowing–emergence, emergence–flowering, flowering–maturity	5.2, 0.7, 5.4	3.59
Kriter	4	Sowing–maturity	5.0	4.58
	4	Sowing–maturity	0.6	2.61
	4	Sowing–flowering, flowering–maturity	0.0, 7.1	3.59
	4	Sowing–emergence, emergence–flowering, flowering–maturity	6.6, 0.0, 7.1	2.73

[z]All base temperatures minimize CV except for 5 °C, which is used commercially.

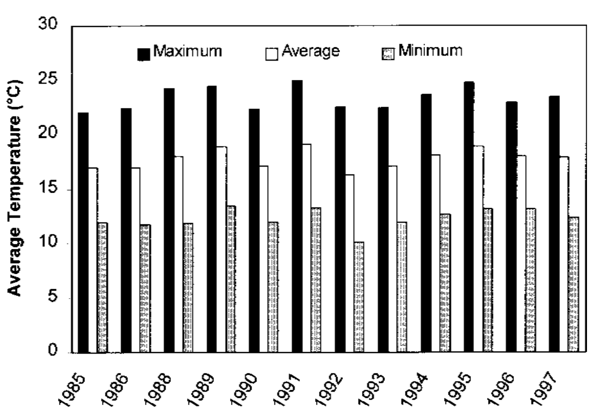

Fig. 1. Average temperatures observed during each growing period at the experimental farm of the Horticultural Research and Development Centre of Agriculture and Agri-Food Canada located at L'Acadie.

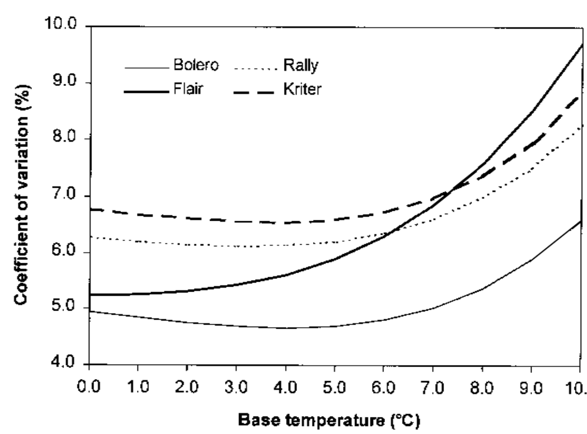

Fig. 2. Evolution of coefficient of variation with base temperatures used in a GDD formula estimating development time from sowing to maturity of four pea cultivars.

maturity were calculated for each cultivar with base temperatures (Tbase) ranging from 0 to 10 °C in steps of 0.1 °C, using a spreadsheet software (Microsoft Excel, Redmond, Wash.). The standard degree-day formula was: GDD = (Tmax + Tmin) × 0.5 – Tbase, where GDD = 0 for GDD < 0. All years with available emergence date from 1985 to 1997 were integrated in the calculation (Table 2). Statistical parameters were calculated from this database for the GDD obtained for each year and cultivar: mean, standard deviation, and coefficient of variation (CV). The base temperatures presenting the lowest CV for: 1) sowing to emergence, 2) sowing to flowering, 3) sowing to maturity, 4) emergence to flowering, 5) emergence to maturity, and 6) flowering to maturity were selected (Arnold, 1959). Coefficients of variance were also calculated for the combination of: 1) sowing to flowering and flowering to maturity, and 2) sowing to emergence, emergence to flowering, and flowering to maturity, using base temperatures that minimized CV for each period.

Results and Discussion

For the first part of the analysis, only years with all stages observed were used. For all cultivars, using a base temperature between 0.0 and 0.8 °C to compute GDD reduced the CV in comparison with 5.0 °C (Table 3), indicating that the base temperature used commercially is probably not the most appropriate for Quebec conditions (CV = 3.62%, 3.60%, 3.62%, and 2.61% for 'Bolero', 'Rally', 'Flair', and 'Kriter', respectively). On the other hand, increasing the complexity of the simple, commercially used model by adding intermediate crop stages, did not substantially reduce the value of the CV. This was especially the case with the second approach where emergence was not considered (CV = 4.10%, 4.33%, 4.13%, and 3.59% for 'Bolero', 'Rally', 'Flair', and 'Kriter', respectively). The third approach gave CV's similar to those from the first approach adapted with a lower base temperature condition (CV = 3.67%, 3.77%, 3.59%, and 2.73% for 'Bolero', 'Rally', 'Flair', and 'Kriter', respectively). Using base temperatures specific for each crop phase did not improve the prediction of maturity in comparison with using an overall base temperature. Therefore, the simplest GDD model with a corrected base temperature was selected for the following steps of the analysis.

All available years for a given cultivar were then used to determine the base temperature with the lowest CV for predicting the time from sowing to maturity (Fig. 2). A base temperature from 0 to 5 °C was generally adequate for all cultivars. The base temperatures with the lowest CV for the cultivars Bolero, Rally, Flair, and Kriter were 4.0, 3.3, 0.0, and 3.7 °C, respectively. The weighted average of 3.0 °C, which considers the number of observations for each cultivar, was selected as a common base temperature for all cultivars.

Four different models to predict harvest dates were then compared in terms of prediction date: 1) average number of days between sowing and maturity, 2) average number of GDD with a base temperature of 5 °C, 3) average number of GDD with an optimal base temperature for each cultivar, and 4) average number of GDD with a base temperature of 3 °C (Table 4). The difference between observed and predicted harvest dates of these four models was calculated (Table 5). The sum of squares of the differences indicated the overall precision of each model prediction for a given cultivar. The GDD approach improved the prediction of the harvest date over model 1 by integrating the effect of

Table 4. Description of selected models to predict harvest date.[z]

	Model 1	Model 2		Model 3		Model 4	
Cultivar	No. days from sowing to harvest	BT	Mean GDD	BT	Mean GDD	BT	Mean GDD
Bolero	63	5.0	800	4.0	863	3.0	926
Rally	59	5.0	749	3.3	849	3.0	867
Flair	57	5.0	713	0.0	996	3.0	826
Kriter	57	5.0	711	3.7	784	3.0	824

[z]Model 2: base temperature (BT) of 5 °C; Model 3: optimal BT for each cultivar; Model 4: BT of 3 °C.

Table 5. Observed and predicted time to maturity of pea cultivars using four selected models.

	Observed day of year at:		Difference between observations and predictions (d)[z] Maturity[y]			
Year	Sowing	Maturity	Model 1	Model 2	Model 3	Model 4
			Bolero			
1986	133	202	–6.0	–3.8	–4.0	–4.2
1989	138	196	5.0	–2.1	–1.7	–1.4
1990	129	200	–8.0	–3.8	–4.1	–4.4
1991	133	191	5.0	–0.5	–0.3	0.0
1992	140	204	–1.0	4.0	3.6	3.2
1993	132	196	–1.0	2.6	2.7	2.0
1994	141	199	5.0	–0.9	–0.7	–0.5
1995	130	189	4.0	0.9	1.0	1.1
1996	130	198	–5.0	–2.7	–2.8	–3.0
1997	142	199	6.0	–0.6	–0.3	0.0
Sum of squares of the differences			254.0	65.5	63.5	63.4
			Rally			
1985	134	200	–7.0	–3.8	–4.1	–4.2
1986	133	202	–10.0	–7.0	–7.5	–7.5
1988	153	207	5.0	–2.0	–1.5	–1.4
1989	138	192	5.0	–1.6	–1.1	–1.0
1990	129	195	–7.0	–2.1	–2.9	–3.0
1991	133	188	4.0	–0.9	–0.6	–0.5
1992	140	199	0.0	4.9	4.0	3.8
1993	132	193	–2.0	1.7	1.3	1.2
1994	141	194	6.0	0.7	1.2	1.3
1995	130	185	4.0	1.7	1.8	1.8
1996	130	193	–4.0	–0.9	–1.3	–1.4
1997	142	197	4.0	–1.5	–1.1	–1.1
Sum of squares of the differences			352.0	108.4	109.5	110.4
			Flair			
1989	138	192	–3.0	–4.1	–2.5	–3.3
1990	129	195	–9.0	–4.9	–6.1	–5.4
1992	140	197	0.0	3.8	2.5	3.2
1993	132	192	–3.0	0.4	–0.6	–0.1
1994	141	194	4.0	–1.9	–0.7	–1.3
1995	130	184	3.0	0.8	1.0	0.9
1997	142	195	4.0	–1.6	–0.6	–1.0
Sum of squares of the differences			140.0	61.1	52.3	54.1
			Kriter			
1985	134	196	–5.0	–1.9	–2.2	–2.4
1986	133	199	–9.0	–7.3	–7.6	–7.7
1988	153	206	4.0	–3.3	–2.8	–2.6
1989	138	189	6.0	–1.2	–0.7	–0.5
1990	129	194	–8.0	–4.0	–4.4	–4.6
1991	133	185	5.0	–0.4	–0.1	0.1
1992	140	197	0.0	3.6	3.2	3.0
1993	132	191	–2.0	1.3	1.0	0.8
1994	141	192	6.0	–0.0	0.4	0.6
1995	130	182	5.0	2.6	2.7	2.7
Sum of squares of the differences			312.0	107.3	109.1	111.2

[z]The decimal value indicates the proportion of a day needed to reach the exact number of GDD.
[y]Based on average days between sowing and maturity (Model 1), average GDD with a base temperature (BT) of 5 °C (Model 2), average GDD with an optimal BT for each cultivar (Model 3), and average GDD with a BT of 3 °C (Model 4).

temperature in the model. However, the three models based on GDD gave very similar results for all cultivars.

For the years and cultivars used in this study, the computation of GDD with a base temperature of 3 °C (model 4) gave an overall prediction of maturity of 2.0, 2.4, 2.2, and 2.5 d based on the average of the absolute values of the differences for the cultivars Bolero, Rally, Flair, and Kriter, respectively (Table 5).

Alhough the study of CV indicated that 5 °C was probably not the most appropriate base temperature for pea cultivars (Table 3), using another base temperature did not improve overall harvest prediction in terms of days (Table 5). However, cultivars appear to differ with regard to base temperature. 'Bolero', 'Rally', and 'Kriter' were quite insensitive to a change in base temperature within a range of 0 to 5 °C, whereas altering the base temperature from 0 °C tended to increase the CV more rapidly for 'Flair' (Fig. 2).

Other parameters, such as soil temperature, soil water content, and sowing depth, need to be investigated to improve harvest prediction. Water stress can indeed affect pea development, the most sensitive moisture periods being just before flowering and during pod enlargement (Maurer et al., 1968; Rubatzky and Yamaguchi, 1997). Furthermore, the division of the growth period into distinct crop stages may eventually lead to a better prediction of harvest. With this approach, crop emergence and flowering need to be clearly defined in terms of crop phenology. For example, defining the flowering stage when 10% or 25% of the plants have at least one fully open flower may affect the precision of the model. Essentially, more precision is needed in the measurement of weather and biological parameters to achieve a better prediction of harvest.

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