Project Title	Understanding coriander bolting: learning from grower experience
Project number:	FV 331
Project leaders:	Dr Jeremy Wiltshire, ADAS UK Ltd
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Location of project:	ADAS Boxworth
Project coordinator:	Mr Bob Herbert, Red Deer Herbs
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Key words:	Coriander, bolting

The results and conclusions in this report are based on a series of experiments conducted over one year. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

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AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

Dr J Wiltshire
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Signature ………………………………… Date ……………………..

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GROWER SUMMARY

Headline

- All current UK varieties of field coriander are likely to bolt, with bolting influenced by environmental and agronomic factors.
- Increasing daylength is a key factor causing bolting but can be little influenced by growers.
- Future efforts should be looking at breeding and selecting for bolt resistant varieties of coriander.

Background and expected deliverables

Background

Bolting of field coriander crops is considered by growers to be unpredictable. Once bolting has been recognised the flowering stem grows very quickly and crop loss can occur with serious financial consequences for the grower.

Factors that growers associate with coriander bolting (in order of importance) are:

- heat
- water stress
- daylength
- vernalisation
- nutrition

Floral initiation in temperate, biennial plants usually has a requirement for low temperature and may be affected by photoperiod. Coriander can behave as a biennial plant (i.e. if sown in autumn and survives the winter, it will flower the next year, but also has annual tendencies (i.e. will flower the same year if sown before autumn). Coriander is a long-day plant, so flowering is induced by long days. There is genetic variation in time from sowing to bolting, and there is a wide range of coriander types used in different climates and for different end products (e.g. seeds or leaves).

Despite the knowledge that coriander bolts in long days, growers perceive that bolting occurs unexpectedly and very rapidly making it difficult to schedule harvests for maximum yield of leaf. Grower experience and crop records could provide useful information to help understand this phenomenon.

Expected deliverables

1. Analyse experience and data from growers to increase knowledge of the environmental factors that cause bolting.

2. Provide the UK industry with recommendations for research and development, based on analysis of information on bolting in coriander.

Summary of the project and main conclusions

The specific objectives of this project were as follows.

1. Gain information on coriander bolting from growers, using a targeted survey.
2. Collect data from growers on bolting in successive coriander sowings in 2008.
3. Provide interpretation to identify implications for UK commercial coriander production.
4. Make research recommendations to allow any further work to be targeted based on existing knowledge.

A survey of grower experience was used to provide information on growers' experience of bolting across a wide geographical area. The questionnaire was followed by telephone interviews of growers who had indicated that they might be willing to participate further in the project. Four growers agreed to collect data in 2008, selected from different areas of Britain to provide different climatic conditions. The locations of the growers were:

- Cornwall (site code C)
- Perthshire (site code P)
- Surrey (site code S)
- Worcestershire (site code W)

Growers were asked to record details of their sequentially sown commercial crops from March to September 2008. Details requested included:

- Soil type
- Variety
- Nitrogen applications
- Irrigation policy/ scheduling method
- Sowing date
- Date when crop becomes un-marketable because of bolting
- Other crop comments, e.g. proportion of ‘early bolters’, drought stress, disease, etc.
- Weather data if available, especially daily maximum and minimum temperatures

The information was analysed to identify key findings and the relevance of these to the industry.

Bolting occurred on three sites (C, S and W). The numbers of crops that bolted at these sites, and mean crop durations for bolted crops are shown in Table 1 for crops of variety Santo that were uncovered.

Table 1 Number of crops (variety Santo only, crops not covered) bolted at each site, and mean times from sowing to bolting.

Site	Number of Santo crops bolted	Mean time from sowing to bolting (days)	Mean time from sowing to bolting (day degrees)
C	8	59	830
P	0	No bolting	No bolting
S	14	56	725
W	4	47	742

Site S was the only site where there were enough bolted and unbolted crops for useful comparison between these. The data show that all the bolted crops had a sowing date before the end of May and all the unbolted crops had a sowing date after the beginning of June. For the unbolted crops the crop duration ended at the last harvest, so it is not known when these crops would have bolted. The average crop duration in days was longer for the bolted crops than for the unbolted crops. However, the crop duration in day degrees showed that the unbolted crops had a longer average duration than the bolted crops.

Analyses of relationships between weather and bolting were restricted to 26 crops of Santo that were not covered and that had bolted. An exponential curve fitted to crop duration (days) plotted against the sowing date showed that crop duration days decreased with later sowing date (Figure 1). However, this relationship was highly influenced by a few crops that had early sowing dates and longer crop duration. For Site S the relationship appears better than for the three sites together, but for prediction of bolting a relationship needs to hold for multiple sites.

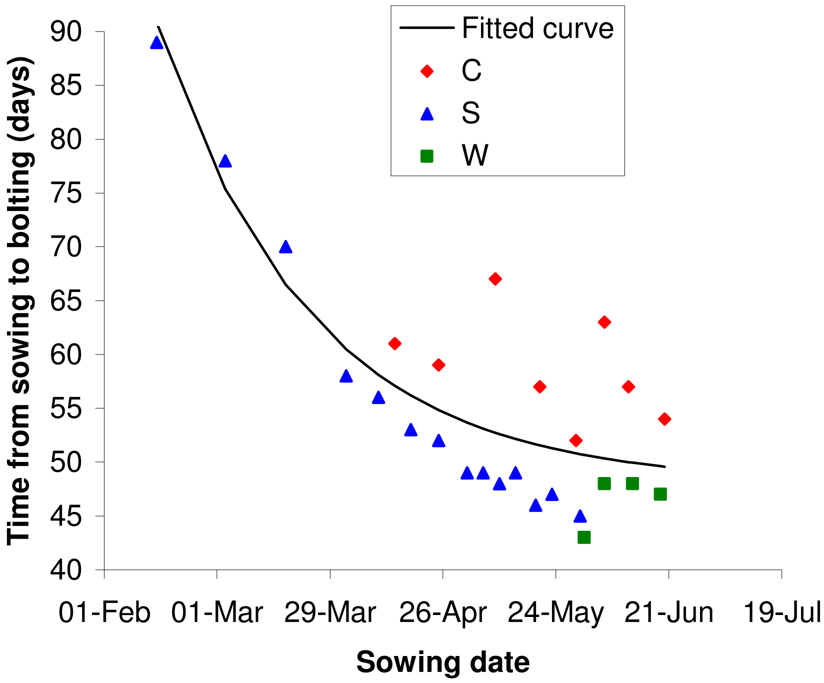


Figure 1 An exponential curve fitted to crop duration (time from sowing to bolting in days) plotted against the sowing date, for 26 crops of variety Santo that were not covered and that bolted, at three sites (C, S and W). Percentage variance accounted for = 71%. Equation of fitted Curve is $48.02+139.6(0.97406^X)$.

A similar analysis using crop duration in units of day degrees did not show a similar relationship.

For crops that bolted, regression analyses showed that time from sowing to bolting (in units of day degrees) was associated with both early season temperature (thermal time in units of day degrees for the first week after sowing) and late season temperature (thermal time in units of day degrees for the last two weeks of the crop growth period). However, the relationships were too variable and not sufficiently consistent between sites to be used predictively.

For crops of Santo that bolted and were not covered, sowing date was more closely related to crop duration in days than to crop duration in thermal time. This suggests that bolting is linked to some aspect of calendar date, such as daylength. It is known that bolting of coriander is induced by long days. Grower experience and results from site S suggest that later crops, growing when days are shortening, do not bolt as quickly as early crops that are growing when days are lengthening.

Effects of daylength on bolting are outside of a grower's control. There is a need for new varieties that have suitable quality characteristics for the market and also exhibit bolting resistance through lower sensitivity to daylength.

More work is needed to better characterise control of bolting and identify traits and phenotypes that are linked to bolting resistance.

Financial benefits

It has been estimated that the area of field coriander grown in the UK is approximately 1,500 ha (Tom Davies, personal communication).

Bolting can cause total loss of early crops because bolting often occurs before the grower anticipates it. The market is then supplied by import substitution. A conservative estimate of yield is 3 t/ha for early crop; import substitution can cost: 3000 kg x £3/kg = £9000 per ha, and 500 ha could easily be sown in this time as the crop will establish well in March / April. Therefore the loss due to bolting could be estimated at between £3M and £4.5M per annum dependent upon number of lost drillings (Tom Davies, personal communication).

If this work leads to future improvements in crop management, such that bolting losses are smaller, there would be financial benefits to the field coriander industry. For example, if the losses estimated above were decreased by 20%, then the savings to the industry would be between £600k and £900k.

Action points for growers

- All crops of field coriander, of current UK varieties, are likely to bolt. Evidence from this project with variety Santo shows that crops sown after the end of May bolt less quickly (in thermal time) than crops sown in May and earlier.

- There is no evidence from this study that early sowings (in March) are at greater risk of bolting than slightly later sowings (in April).

- Keep records of days from sowing to bolting. Records accumulated over several years could show how time to bolting changes with sowing date, and might help growers to better anticipate onset of bolting.

SCIENCE SECTION

Introduction

Bolting of field coriander crops is considered by growers to be unpredictable. Once bolting has been recognised the flowering stem grows very quickly and crop loss can occur with serious financial consequences for the grower.

Factors that growers associate with coriander bolting (in order of importance) are:

- heat
- water stress
- daylength
- vernalisation
- nutrition

Floral initiation in temperate, biennial plants usually has a requirement for low temperature and may be affected by photoperiod. Coriander can behave as a biennial plant (i.e. if sown in autumn and survives the winter, it will flower the next year, but also has annual tendencies (i.e. will flower the same year if sown before autumn). Coriander is a long day plant (Palamar & Chotina, 1953; Konstantinov & Zhebrak, 1963; Alborishvilli, 1971), so flowering is induced by long days. There is genetic variation in time from sowing to bolting, and there is a wide range of coriander types used in different climates and for different end products (e.g. seeds or leaves).

Despite the knowledge that coriander bolts in long days, growers perceive that bolting occurs unexpectedly and very rapidly making it difficult to schedule harvests for maximum yield of leaf. This project aimed to use grower experience and crop records to provide useful information to help understand this phenomenon. Growers plant successive crops, and this commercial work is a useful source of information on effects of environment and agronomy on bolting.

In other species related to coriander, such as celery, bolting has been well characterised in relation to environmental triggers, and the information has provided commercial advantages. For example, the minimum physiological age for celery bolting is 714 to 840 °C days above 3°C (depending on variety), equivalent to a growth stage of 17 to 20 leaves (Ramin & Atherton, 1991). Vernalisation occurs at below 14°C (Benoit *et al.*, 1978; Pressman & Sachs, 1985), and the optimal temperature range is 5 to 9°C (Honma, 1959; Kinet *et al.*, 1976).

Bolting can be delayed by long days during vernalisation (Pressman & Negbi, 1980), and by either temperatures above 16℃ (Benoit *et al.*, 1978), or short days after vernalisation (Ramin and Atherton, 1994). The latter effect is called devernalisation.

Early bolting detection is possible in celery and has helped growers by allowing early harvest before crop loss. Visual and microscopic criteria are used for early detection of bolting (Jenni *et al.*, 2005).

Scope and objectives

The scope of this work was to analyse experience and data from growers to increase knowledge of the environmental factors that cause bolting, and to provide the UK industry with recommendations for research and development, based on analysis of information on bolting in coriander.

The specific objectives of this work were:

- Gain information on coriander bolting from growers, using a targeted survey.
- Collect data from growers on bolting in successive coriander sowings in 2008.
- Provide interpretation to identify implications for UK commercial coriander production.
- Make research recommendations to allow any further work to be targeted based on existing knowledge.

Materials and Methods

A questionnaire was designed in consultation with the project co-ordinator (see Appendix 1). The questionnaire was sent to herb growers by HDC.

Returned questionnaires were used to select a shortlist of growers, who were telephoned prior to selection of four growers who then collected data for the project in 2008. These four growers were selected from different areas of Britain to provide different climatic conditions. The locations of the growers were:

- Cornwall
- Perthshire
- Surrey
- Worcestershire

Growers were asked to record details of their sequentially sown commercial crops from March to September 2008. Details requested included:

- Soil type
- Variety
- Nitrogen applications
- Irrigation policy/ scheduling method
- Sowing date
- Date when crop becomes un-marketable because of bolting
- Other comments on crop, e.g. proportion of ‘early bolters’, drought stress, disease, etc.
- Weather data if available, especially daily maximum and minimum temperatures.

Data sheets were provided to simplify data collection and recording, either as paper sheets, or in an electronic format, to the grower’s preference.

The growers were asked to record details of their sequentially-sown commercial crops from March to September 2008. Details requested included:

- Soil type
- Previous crop
- Variety
- Nitrogen applications
- Irrigation policy/ scheduling method
- Sowing date
- Date when crop becomes un-marketable because of bolting
- Other comments on crop, e.g. proportion of ‘early bolters’, drought stress, disease, etc.
- Weather data if available, especially daily maximum and minimum temperatures

Meteorological data were obtained from local weather stations for three sites, and were provided by the grower for one site.

The information was analysed to identify key findings and the relevance of these to the industry. Data were summarised using descriptive statistics and regression analyses.

Results

Questionnaire

Questionnaires were received from 31 growers and 12 were growers of field coriander. Nine of these were willing to participate in the project. Of these nine growers, three were unsuitable (small area, or growing only under polythene, or cutting the crop too young). Of the remaining six growers, four were selected based on geographical location and these agreed to collect data. The locations of the growers were:

- Cornwall (site code C)
- Perthshire (site code P)
- Surrey (site code S)
- Worcestershire (site code W)

Data collection from sequentially sown crops

The data requested from growers are listed in the Materials and Methods section above. In total data were received for 84 crops. The data sets are summarised in Table 2.

Table 2 Summary of data sets received from growers.

Data set characteristic	Site C	Site P	Site S	Site W
Total number of crops	26	4	40	14
Number of crops used in data analyses	14	4	36	7
Number of varieties	4	2	1	2
Number of crops covered	1	1	0	3
Earliest sowing	19-Mar	14-Apr	15-Feb	10-Apr
Latest sowing	24-Jul	5-Aug	25-Aug	6-Aug
Soil type	Clay loam	Sandy loam	Sandy loam	Sandy loam
Irrigation (Y/N)	Y	Y	Y	Y

Some data sets were rejected from the analysis because of incomplete data, for example, no information on variety, sowing date, whether bolting occurred, or final harvest date. There were 61 crops with good data for crop duration and incidence of bolting. Of these, 56 crops were not covered, and 28 were not covered and bolted.

Information on nitrogen fertiliser applications and irrigation was collected, but were not used in statistical analyses. The fertiliser application rates had a small range and these data were confounded with other variables (e.g. site, sowing date). All crops were irrigated if required to minimise water stress.

Variety and bolting

Of the 28 crops with good data, and that bolted and were not covered, 26 were variety Santo, one was variety Filtro and one was variety Delphino. The range of crop durations was 657 to 941 day degrees (^{o}C). The Filtro crop had a duration of 682 day degrees (Site C, a mid-season crop sown on 20 May) and the Delphino crop had a duration of 941 day degrees (Site C, a later crop sown on 5 June), equal longest with a crop of Santo.

Site and bolting

Bolting occurred on three sites (C, S and W). The numbers of crops that bolted at these sites, and mean crop durations for bolted crops are shown in Table 3 for crops of variety Santo that were not covered.

Table 3 Number of crops (variety Santo only, crops not covered) bolted at each site, and mean times from sowing to bolting.

Site	**Number of Santo crops bolted**	**Mean time from sowing to bolting (days)**	**Mean time from sowing to bolting (day degrees)**
C	8	59	830
P	0	No bolting	No bolting
S	14	56	725
W	4	47	742

The average thermal time from sowing to bolting, for variety Santo, varied between sites: crop duration in thermal time was longest at Site C and shortest at Site S.

Comparison between bolted and unbolted crops

Site S was the only site where there were enough bolted and unbolted crops for useful comparisons to be drawn between them. The data show that all the bolted crops had a sowing date before the end of May and all the unbolted crops had a sowing date after the beginning of June. For the unbolted crops the crop duration ended at the last harvest, so it is not known when these crops would have bolted.

The average crop duration in days was longer for the bolted crops than for the unbolted crops at Site S where most observations were taken (Table 4). However, the crop duration in day degrees showed that the unbolted crops had a longer average duration than the bolted crops (Table 5).

Table 4 Crop durations (days) for unbolted and bolted crops.

Site	**Unbolted**		**Bolted**	
	Number of crops	**Mean crop duration (days)**	**Number of crops**	**Mean crop duration (days)**
C	3	60	11	59
P	4	62	0	Not applicable
S	22	50	14	56
W	0	Not applicable	7	48

Table 5 Crop durations (day degrees) for unbolted and bolted crops.

Site	**Unbolted**		**Bolted**	
	Number of crops	**Mean crop duration (day degrees)**	**Number of crops**	**Mean crop duration (day degrees)**
C	3	923.6	11	809.8
P	4	815.7	0	Not applicable
S	22	803.2	14	725.1
W	0	Not applicable	7	708.7

Effects of weather on time from sowing to bolting

An exponential curve was fitted to crop duration (days) plotted against the sowing date for all crops that bolted (data not shown). This showed that crop duration days decreased with later sowing date. However, this relationship was highly influenced by a few crops that had early sowing dates and longer crop duration. A similar analysis using crop duration in units of day degrees did not show a similar relationship and the fit was very poor (data not shown).

These analyses were repeated for crops of variety Santo that were not covered and that bolted, a total of 26 crops. An exponential curve fitted to crop duration (days) plotted against the sowing date showed that crop duration days decreased with later sowing date (Figure 2). There was an improved fit compared with the analysis that included all bolted crops (data not shown) because much of the variability at later sowing dates has been removed (Figure 2). However, this relationship was highly influenced by a few crops that had early sowing dates and longer crop duration. For Site S the relationship appears better than for the three sites together, but for prediction of bolting a relationship needs to hold for multiple sites.

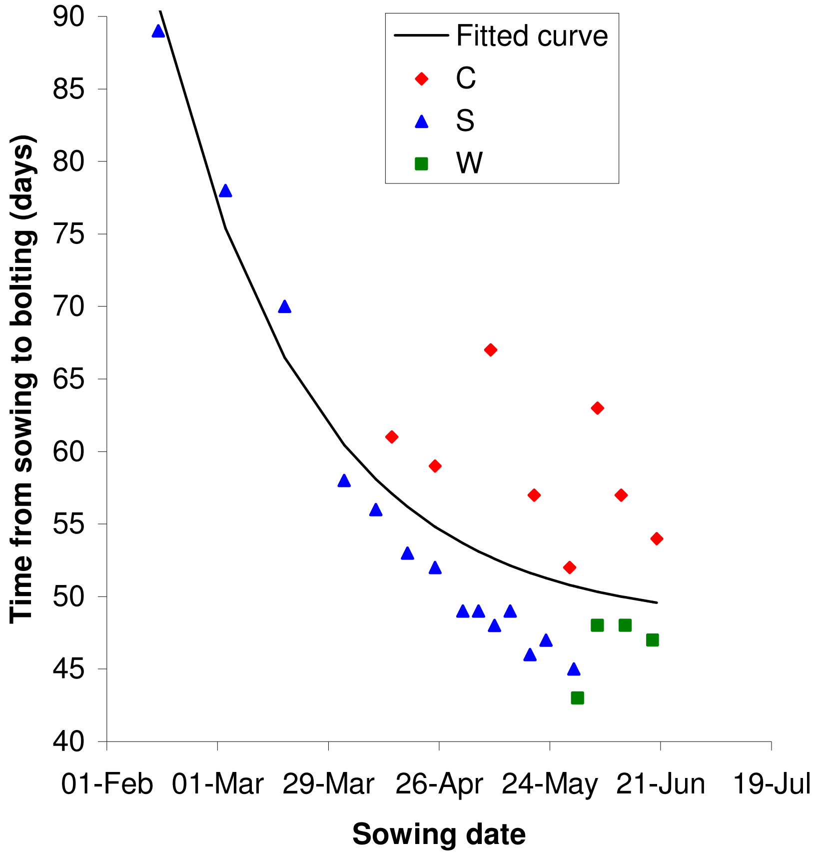


Figure 2 An exponential curve fitted to crop duration (time from sowing to bolting in days) plotted against the sowing date by nonlinear regression analysis, for 26 crops of variety Santo that were not covered and that bolted, at three sites (C, S and W). Percentage variance accounted for =71.0. Standard error of observations is estimated to be 5.81. Fitted Curve: $48.02+139.6(0.97406^{X})$.

A similar analysis using crop duration in units of day degrees did not show a similar relationship (Figure 3). The fit was poor and the fitted curve indicates that crop duration increased as sowing date became later. The analysis shows that the fitted line explains only 4.9% of the variability.

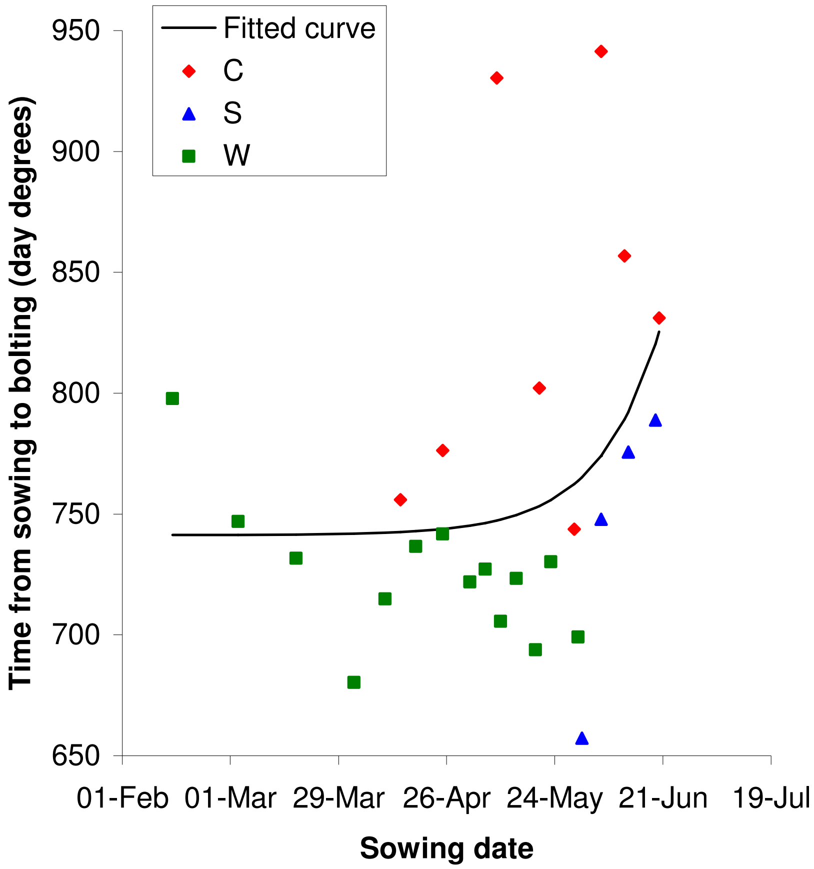


Figure 3 An exponential curve fitted to crop duration (time from sowing to bolting in day degrees) plotted against the sowing date by nonlinear regression analysis, for 26 crops of variety Santo that were not covered and that bolted, at three sites (C, S and W). Percentage variance accounted for =4.9.

A regression analysis was then done on crop duration (time from sowing to bolting in units of days and day degrees) plotted against weather variables including minimum and maximum temperatures, thermal time (day degrees) for each week of the crop, for the first half of the crop duration, the second half of the crop duration, the first six weeks of the crop and the last two weeks of the crop. These variables were chosen based on anecdotal evidence from growers that bolting may be influenced by early-season low temperatures and late season high temperatures. These parameters were put into a regression analysis, along with a site factor, using Genstat, to see which parameters had the largest influence on crop duration.

The regression showed that it was important to take site out of the analysis, and then that the most important factor was thermal time (day degrees) for the second half of the crop duration. It is not surprising that either this or the thermal time in the first half of the season should be having a large influence, because crop duration and thermal time in the second half of the season are not independent. It would be expected that if the thermal time in the second half of the season was large, that the overall crop duration in thermal time would also be large. Once it was decided that the second half of the growth period was more important than the first half, the analysis was then repeated to see what other parameters added more information. It was not sensible to include thermal time in the first half of the season in the new regression, because, if both thermal time in first half and second halves had been included we would have included two parameters that had all the information about the total thermal time. The analysis showed that next most important parameter was thermal time in the first week after sowing. This was slightly better than minimum temperature, and when thermal time in the first week after sowing was included in the analysis there was no benefit in including minimum temperature. This is because there was a relationship between minimum temperature and thermal time in the first week after sowing. This regression analysis can be found in Appendix 2.

Regression analysis

Response variate: crop_duration (day degrees)
Fitted terms: Constant + Site + dd_second_half + dd_wk1

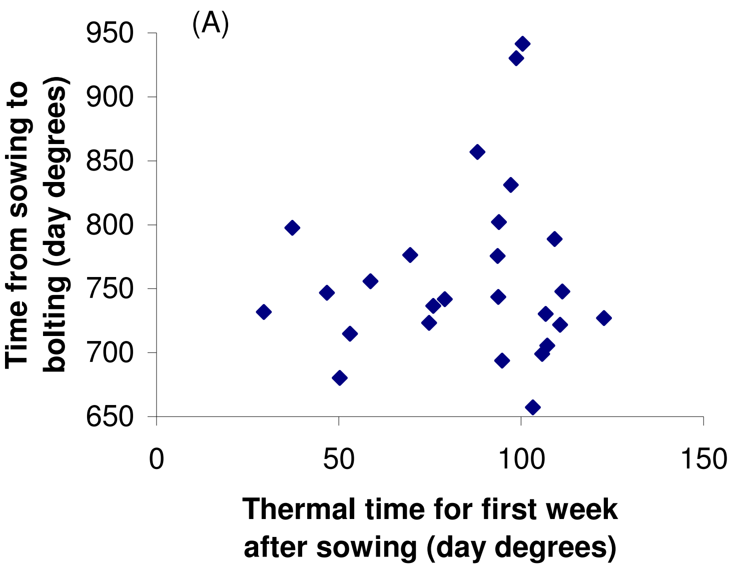
The analysis summarised in Appendix 2 explains 84.7 % of the variation. The fitted equation is:

Duration (day degrees) = Site + 1.182(dd_second_half) + 1.122(dd_wk1)

where 'Site' is 187.2 for Site C, 146 for Site S and 250 for Site W; 'dd_second_half' is thermal time (day degrees) for the second half of the crop duration; and 'dd_wk1' is thermal time in the first week after sowing.

None of the other metrological parameters were of use in predicting the crop duration.

Because of anecdotal evidence from growers that bolting may be influenced by early season low temperatures (thermal time in units of day degrees for the first week after sowing) and late season high temperatures (thermal time in units of day degrees for the last two weeks of the crop), these temperature variables are plotted against time from sowing to bolting (Figure 4) to allow visual inspection of the data. These graphs confirm that neither early season low temperatures nor late season high temperatures were useful as predictors of crop duration (time from sowing to bolting in units of day degrees). In both cases the full range of crop durations is possible at some values of thermal time.



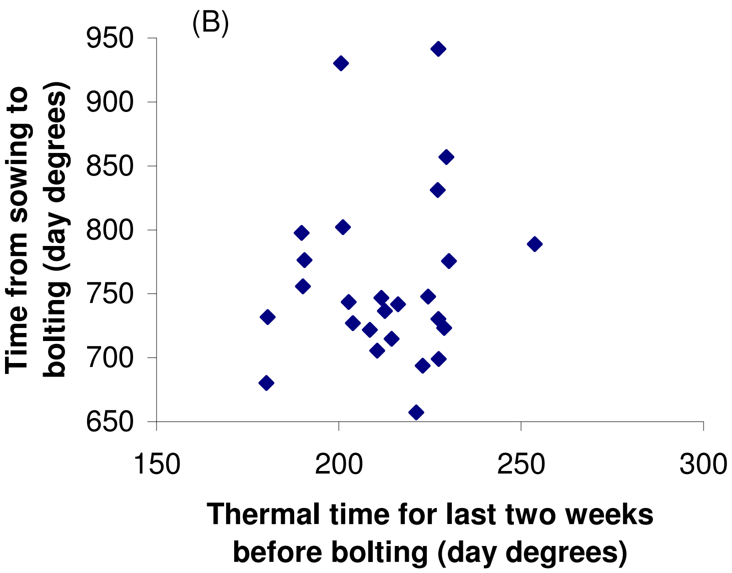


Figure 4 Scatter plots of (A) early season temperature (thermal time in units of day degrees for the first week after sowing) and (B) late season temperature (thermal time in units of day degrees for the last two weeks of the crop growth period), against time from sowing to bolting (day degrees).

Discussion

The average thermal time (degree days = °C d) from sowing to bolting for variety Santo varied between sites: crop duration in thermal time was longest at Site C (830 °C d) and shortest at Site S (725 °C d). These differences are large enough to be of commercial significance and suggest that bolting is influenced by environmental and/or agronomic factors.

For crops of Santo that bolted and were not covered, sowing date was more closely related to crop duration in days than to crop duration in thermal time. This suggests that bolting is linked to some aspect of calendar date, such as daylength. It is known that coriander is a long day plant (Palamar and Chotina, 1953; Konstantinov and Zhebrak, 1963; Alborishvilli, 1971), so flowering is induced by long days. Grower experience and results from site S suggest that later crops, growing when days are shortening, do not bolt as quickly as early crops that are growing when days are lengthening.

Effects of daylength on bolting are outside of a grower's control. There is a need for new varieties that have suitable quality characteristics for the market and also exhibit bolting resistance through lower sensitivity to daylength.

In the data sets reported here there was not enough variety variation to study differences in susceptibility to bolting. For 28 crops that bolted and were not covered, 26 were variety Santo, one was variety Filtro and one was variety Delphino. Both Filtro and Dephino had crop durations within the range for Santo (657 to 941 day degrees), although Filtro was near the bottom of the range and Delphino was at the top of the range. More work is needed to better characterise control of bolting and identify traits and phenotypes that are linked to bolting resistance.

Conclusions

- All crops of field coriander, of current UK varieties, are likely to bolt. Evidence from this project with variety Santo shows that crops sown after the end of May bolt less quickly (in thermal time) than crops sown in May and earlier.
- There is no evidence from this study that early sowings (in March) are at greater risk of bolting than slightly later sowings (in April).

- More work is needed to better characterise control of bolting and identify traits and phenotypes that are linked to bolting resistance.
- Effects of daylength on bolting are outside of a grower's control. There is a need for new varieties that have suitable quality characteristics for the market and also exhibit better bolting resistance than current UK varieties.

Research recommendations

- More work is needed to better characterise the factors that control bolting in coriander. This should be done by controlled experiments to avoid confounding between multiple factors that might affect bolting.
- Work that is designed to identify traits and phenotypes that are linked to bolting resistance would help breeders to develop bolting-resistant varieties for the UK market.
- There is a need for breeding to develop new varieties that have suitable quality characteristics for the market and also exhibit better bolting resistance than current UK varieties.

Acknowledgements

This study would not have been possible without the participation of herb growers. The author thanks all growers who participated in this study by completing the questionnaire. Special thanks are given to four growers who gave their time to collect data from sequentially-grown crops.

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- Tom Davies of Malvern View Herbs for provision of meteorological data and for estimates of financial losses caused by bolting.
- Chris Dyer, ADAS Statistician, for statistical analysis of data.

Technology transfer

- Project final report.
- Article in HDC news, summarising key findings with implications for the UK industry (planned).

References

Alborishvilli, C.A. 1971. Variability of economic and biological characters of lettuce and coriander cultivars in relation to sowing date [in Russ., Eng. abstr.]. Trudy po Prikladnoi Botanike, Genetike i Selekcii 45, 216-227. (cited in HDC report for project FV 331)

Benoit, F., J.M. Kinet, and N. Ceustermans. 1978. Induction, suppression or prevention of vernalisation in self-blanching celery (*Apium graveolens* L. var. *dulce*). Agricultura 26: 163–182.

Honma, S. 1959. A method for evaluating resistance to bolting in celery. Proc. Amer. Soc. Hort. Sci. 74: 506–513.

Jenni, S., I. Gamache, J.C. Côté, and K.A. Stewart. 2005. Early Field Detection of Bolting in Celery. HortTechnology 15: 1-3.

Kinet, J.M., F. Benoit, N. Ceustermans, and A. Parmentier. 1976. Environmental control of bolting and flowering in selfblanching celery (*Apium graveolens* L. var. dulce) by exposure to low temperature. Agricultura 24: 347–358.

Konstantinov, N.N. and E.A. Zhebrak. 1963. Photoperiodism in diploid and tetraploid coriander. Doklady Akademii Nauk SSSR 150, 1149-1152. (cited in HDC report for project FV 331)

Palamar, N.S. and A.A. Chotina. 1953. Koriandr (Coriander). Moskva: Gosudarstvennoe izdatel'stvosel'skochozjaistvennoj literatury. (cited in HDC report for project FV 331)

Pressman, E. and M. Negbi. 1980. The effect of day length on the response of celery to vernalization. J. Expt. Bot. 31: 1291–1296.

Pressman, E. and M. Sachs. 1985. *Apium graveolens*, p. 485–507. In: A.H. Halevy (ed.). Handbook of flowering, Vol. I. CRC Press, Boca Raton, Fla.

Ramin, A.A. and J.G. Atherton. 1991. Manipulation of bolting and flowering in celery (*Apium graveolens* L. var. *dulce*). II. Juvenility. J. Hort. Sci. 66: 709–717.

Ramin, A.A. and J.G. Atherton. 1994. Manipulation of bolting and flowering in celery (*Apium graveolens* L. var. *dulce*). III. Effects of photoperiod and irradiance. J. Hort. Sci. 69: 861–868.

Appendix 1.

The questionnaire is reproduced on the following three pages.

Field coriander bolting survey

Section A

1 Contact details

Your name/ nursery					
Name Address					
Post code					
Telephone		Mobile		Fax	
E-mail					

Section B

2 What is the approximate annual area of your field coriander crop (including re-sowing)?

....

3 Which varieties of coriander do you grow?

....

....

....

....

4 Typically, what are your earliest and latest coriander sowing dates?

Typical earliest coriander sowing date: ....

Typical latest coriander sowing date: ....

5 How many coriander sowing dates do you aim to have in each season?

- 1 -

6 Coriander bolting

a) Do you have a problem with bolting?

Yes	No

b) If Yes, does bolting sometimes occur earlier than you expect?

Yes	No

c) If you have any comments about coriander bolting, please enter them in the box below.

7 Crop records

For coriander crops, do you keep records of:

	Yes	No
Sowing dates		
Harvest periods for each crop		
Dates when bolting occurs		
Fertiliser applications		
Irrigation		

- 2 -

8 What is your soil type?

……………………………………………………………………………………………

9 Learning more about coriander bolting

Would you be willing to participate in a study of coriander bolting, by recording details of your crops (e.g. sowing dates, fertiliser applications, dates bolting first observed)

Yes	No

Note: *If you tick "Yes", you may receive a telephone call from ADAS to discuss your coriander crops and how they could be used to study bolting. This could help your business by helping you to understand bolting risk.*

10 Please add any other comments or information which you consider important, in the box below

11 Please check that you've completed all sections and return in the pre-paid envelope provided to the HDC 14 December 2007.

Thank you for your co-operation.

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Appendix 2.

Regression analysis

Summary of analysis:

Source	Degrees of freedom	Sum of squares	Mean square	Variance ratio	F prob. (statistical significance)
Regression	4	102761	25690.3	35.52	<.001
Residual	21	15187	723.2		
Total	25	117949	4717.9		

Estimates of parameters:

Parameter	estimate	s.e.	t(21)	t prob. (statistical significance)
Constant	187.2	83.3	2.25	0.036
Site S	-41.2	14.5	-2.84	0.010
Site W	-62.8	17.2	-3.65	0.002
dd_second_half	1.182	0.149	7.93	<.001
dd_wk1	1.122	0.264	4.25	<.001

Accumulated analysis of variance:

Change	Degrees of freedom	Sum of squares	Mean square	Variance ratio	F prob. (statistical significance)
+ Site	2	57200.9	28600.5	39.55	<.001
+ dd_second_half	1	32492.6	32492.6	44.93	<.001
+ dd_wk1	1	13067.7	13067.7	18.07	<.001
Residual	21	15187.3	723.2		
Total	25	117948.6	4717.9		