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AUTHENTICATION

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

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Grower Summary

Headline

Thirty one new 'leafy' coriander varieties have been identified for the pot and field grown industry and the effects of changes in growth conditions on their appearance, harvest window and shelf-life studied. This provides a range of opportunities for growers to expand the existing market.

Background and expected deliverables

Development and expansion of the market for fresh coriander is restricted by its extreme perishability. Coriander was recognised as the most problematic herb in terms of shelf-life, habit and flavour persistence at a 'Steering Group' meeting of the BHTA growers, attended by members of the HDC and researchers in 2005. The short shelf-life is the result of the ontogenetic programme of this species – the leaves in the basal rosette die quickly after production of a flowering stem. This ontogenetic feature creates problems for coriander herb growers: the flavour of senescing leaves is poor, the harvesting window is short and production of green biomass is low. However, it is possible to extend the shelf life of coriander using the natural biodiversity of the species.

Varieties of coriander developed for their leaves as a vegetable have two potential benefits compared to varieties bred for their fruits: firstly, the leaves live longer, and secondly, the plants look luxuriant.

Thus, a first objective was to identify new 'leafy' varieties of coriander and contrast their appearance and shelf life with current commercial varieties.

A second objective was to evaluate the effects of changes in conditions (nutrition, temperature, light, stress) on the growth and appearance of 'leafy' varieties of coriander and determine if a simple treatment could extend the shelf life.

Summary of the project and main conclusions

Forty eight promising varieties in terms of appearance and harvesting window were selected from a collection at the N. I. Vavilov Research Institute of Plant Industry (VIR) in St Petersburg, based on a literature survey, studies in the VIR Herbarium and consultations with the Curator of Collection.

Most of the varieties we used (35) originated from the Caucasus, because a study of plant material in the VIR herbarium showed that this region is exceptionally rich in 'leafy' varieties. Accessions from Asia (7) were carefully selected and only varieties known as 'leafy' were sourced. Six varieties of mixed origin were obtained as they were known from the literature to be 'leafy'.

Objective 1:

a) Identifying the best 'leafy' varieties for field herb growers

Discussions at BHTA meetings in 2005-2006 showed that the most important characteristics for field growers are time of bolting and number and size of leaves. Identification of 'leafy' varieties for the field industry was based on a single summer trial in soil in a glasshouse (trialled once in summer 2006 or 2007 depending on time when seeds were obtained from VIR). Informal tasting of all varieties grown in soil was conducted, but no decision to reject a variety was made based on this single assessment. A description of the flavour of each variety is given in Table 4 of the main report.

Sixteen varieties were selected from this trial for field growers. Pictures of these varieties and short descriptions of their characteristics, when grown in soil, can be found in

Appendix A attached to the report. The selected 'field' varieties can be divided in two groups.

- **Late-bolting varieties**[1]

  This group includes varieties, which bolt later than 35th day from germination in summer: K-23, K-43, K-52, K-66, K-92, K-103, K-148, K-157 and K-165. Variety K-43 is exceptionally tolerant to bolting. All selected varieties have a typical leaf size, a high number of leaves in the rosette, strong petioles and a good overall appearance and colour.

- **Medium-bolting varieties with big leaves**

  This group includes varieties K-60, K-62, K-101, K-150, K-213, K-288 and K-317. They are at risk of bolting from the 25th-30th day from germination in hot summers, so for places where bolting might be an issue these varieties should be trialled *in situ*. For spring and autumn sowing these varieties are highly suitable. We recommended growing these varieties wherever possible, because they have remarkably big leaves and strong thick petioles.

b) Identifying the best 'leafy' varieties for <u>pot herb growers</u>

Visual appearance, number of leaves in the basal rosette and time of bolting of all 48 varieties sourced from VIR were assessed in a glasshouse in soil (summer 2006 or 2007 depending on the date when seeds were obtained from VIR). As a result, 35 varieties were found promising (see the Appendix A attached to this report) and 13 were rejected.

The promising varieties of coriander were propagated for seeds. Most varieties (33) produced sufficient seeds for further trials, but varieties K-202 and K-213 did not. Varieties K-103, K-148 and K-157 produced many seeds but their germination was poor.

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[1] Bolting time is given for the greenhouse used in Sussex. Bolting time in the field, where summer temperatures are lower, than in the greenhouse, will be prolonged.

After propagation the promising varieties were tested in pots a glasshouse where plant height, leaf area, hypocotyl length, dry weight, appearance of petioles, number of leaves in the rosette at harvest and at bolting, time of bolting and length of harvesting window were recorded. Varieties currently used by the industry, *Americanum* and *Kashmir*, were used as controls. Informal tasting of all varieties was undertaken and only one (K-5) was rejected on the grounds of poor flavour. A full description of the characteristics of the 35 trialled varieties is given in Appendix B of the main report.

Finally, from 35 promising varieties, 15 were selected for pot growers (K-4, K-23, K-43, K-58, K-60, K-61, K-64, K-66, K-92, K-103, K-133, K-157, K-165, K-202 and K-317; see Fig. 1) as they out-competed controls on appearance and harvesting window. Based on the performance of the 15 selected varieties in different seasons, we divided them into three groups and recommend them for use according to the season.

- **Summer varieties**

  These are medium- to late-bolting varieties that have a longer harvest window than *Americanum* and *Kashmir*. These varieties flourished in summer, had strong upright petioles and fully expanded non-scorched green leaves. These characteristics give these varieties an advantage over *Americanum* and *Kashmir*, as both industry controls suffered in summer: they bolted early (sometimes before they reach a harvestable stage), often had stunted petioles and scorched leaves. In winter, these selected summer varieties looked as poor as controls having stretched floppy petioles. Selected summer varieties are: K-103, K-157 and K-202 (Fig. 1).

- **Winter/ autumn/ spring varieties**

  These varieties had a good appearance and harvest window in cool seasons with rather short days. Use of such varieties by the industry would only be justified if their appearance were better than currently used controls in cool seasons. Thus, varieties with stronger petioles, bigger leaves, higher number of leaves in the rosette, shorter hypocotyls and a longer harvest window were selected and recommended for use in winter/ spring/ autumn: these are K-4, K-60, K-61 and K-64 (Fig. 1).

- **All season varieties**

  These are medium to late-bolting varieties. They performed rather evenly through the seasons, although there was some occasional scorching in summer or stretched floppy petioles in winter. Again, from these varieties only the best were selected based on vegetative characteristics (stronger petioles, higher number of leaves in the rosette and shorter hypocotyls) and with a longer harvest window than that of the controls: those recommended are K-23, K-43, K-58, K-66, K-92, K-133, K-165 and K-317 (Fig. 1).

The harvest window is a very important characteristic of pot-grown coriander as it shows the time period when leaf yellowing and withering has not yet started to spoil the appearance of the herb. The longer the harvest window, the longer the herb can be displayed on a supermarket shelf. We found that for medium-bolting varieties, the harvest window in summer/late spring/early autumn was usually limited by bolting, and in winter by leaf ageing. From 15 selected varieties, 7 were medium-bolting: K-4, K-58, K-60, K-61, K-64, K-133, K-202 and K-317. We recommend growers check the harvest window *in situ* as bolting of coriander depends on light and temperature, and temperature buffering and light control in our greenhouse may differ from that in large commercial greenhouses.

Fig.1 Two currently used coriander varieties (*Kashmir* and *Americanum*) and 15 'leafy' varieties selected for pot growers.

Kashmir

Americanum

K-4

K-23

K-43

K-58


K-60


K-61


K-64


K-66


K-92


K-103


K-157

K-133	
 K-165	 K-202
 K-317	

Objective 2:

Identifying growth conditions that improve the growth of pot-grown 'leafy' varieties

It became clear early in the project that coriander is very sensitive to light and/or space availability. We noticed that if germination of a particular variety were, for some reason, lower than that in an industry control, the smaller number of plants did not spoil the final appearance of the pot, but often improved it as the plants looked stronger.

We therefore investigated if light and space availability were beneficial for the development of coriander leaf rosettes. For this purpose, 'leafy' varieties K-4, K-43, K-58, K-60 and K-64 were tested with the industry variety *Kashmir* used as a control. Varieties were sown in medium round pots (diameter, 10 cm) either at high density of 36 fruits/pot = 0.5 fruit/cm^2 or at low density of 18 fruits/pot.

We found that at the lower sowing density, leaf area, plant dry weight and number of leaves in the rosette increased in all varieties, although the increase was not always statistically significant. Nevertheless, the tendency was very clear: leaves and leaf rosettes developed better when plants were spaced out. Also, at the lower sowing density, hypocotyl elongation stopped earlier and hypocotyl length was significantly less than at the higher sowing density. A short hypocotyl is very important for coriander as it ensures rosette stability: long hypocotyls make the rosette unstable and droopy. We would therefore recommend a change in practice to planting coriander varieties at a lower density than is currently used by industry.

Shelf-life is another very important characteristic of pot-grown coriander as it reflects how long plants will survive without watering on a supermarket shelf. We therefore tested if shelf-life of coriander plants depends on genotype. Three 'leafy' varieties – K-4, K-43, and K-60 – and both the standard industry varieties as controls were grown in pots which were packed in polyethylene sleeves. Fresh weight was measured every day and the day wilting was apparent was recorded for every pot. There was no difference in water loss from pots with different varieties grown on different peat mixtures.

Whilst we did not find differences in drought resistance between coriander genotypes, we did discover a treatment which may help coriander to survive longer on the supermarket shelf. When small quantities of sodium sulphate were added to the nutrient solution (final concentration 1.6 g/l which is 12.5 mM) elongation of shelf-life was staggering: plants in pots treated with sodium sulphate wilted much later than non-treated plants and shelf-life increased between 33% and 170% (1-7 days) depending on substrate and variety. The addition of sodium sulphate to the nutrient solution improved the apparent strength of the petioles: in non-treated pots 70% of plants showed a floppy appearance; in treated pots 70% of plants were upright.

It is therefore recommended that growers consider adding sodium sulphate to nutrient solutions to ensure a better appearance of coriander and a longer shelf-life. Some adjustments of the concentration might be needed due to different growth conditions in commercial and experimental greenhouses. As it is not always possible to feed coriander separately from other herbs, growers should check if sodium sulphate has a positive effect on the appearance and shelf-life of other herbs. For hydroponic- and container-grown ornamentals and leafy vegetables, addition of low concentrations of sodium sulphate may also be beneficial as it is likely to improve their shelf-life.

In summary

- Sixteen 'leafy' coriander varieties suitable for the **field** industry were identified from a collection of 347 accessions at the N. I. Vavilov Research Institute of Plant Industry (VIR), Russia.
- This selection provides a range of opportunities for **field** growers: if bolting is a major concern 'late-bolting' varieties should be sown, if high biomass is desirable, 'medium-bolting varieties with big leaves' should be sown.
- Fifteen 'leafy' coriander varieties suitable for the **pot** herb industry were identified – again providing a range of options for growers. Several varieties were resistant to summer heat in the greenhouse and long days, several to temperature and day length fluctuations and several varieties had exceptionally large leaves and high biomass; other varieties showed reduced flopping of petioles.
- All the varieties selected had a better appearance and harvest window than those currently used by **pot** growers. Several out-competed the industry standard varieties on leaf size and biomass.
- Treatments were found which improved the development of the rosette, the strength of petioles and the shelf-life.

Financial benefits

For pot coriander growers an increase of 5% - 10% in national sales is highly achievable if the varieties identified can be obtained and grown successfully. These varieties will allow a significant improvement in shelf-life and an increase in quality, two factors that will enable market expansion.

Action points for growers

- The 15 new 'leafy' coriander varieties identified for the pot-grown industry and 16 for the field industry need to be obtained from VIR for use by the UK industry.

- Growers/seed houses should be aware that multiplication might be needed before any trials take place as VIR only provides about 200 fruits of each variety.

- Varieties sourced should be trialled *in situ* for a year and important characteristics monitored. For example, for field growers: bolting, harvest window, biomass and disease susceptibility and for pot growers: flopping, harvest window, shelf-life and disease susceptibility.

- For optimal growth and rosette development, growers should try sowing coriander plants at low density (0.25-0.3 fruits/cm^2 in pots).

- For longer shelf-life and stronger petioles pot-grown plants should be treated with 1.6 g/l sodium sulphate in nutrient solution applied at the appearance of the second true leaf in the rosette.

Science Section

Introduction

Development and expansion of sales in fresh herbs have been restricted by their extreme perishability and the limited knowledge of best handling and storage practices (Chennell, Tomkins and Franz, 1999). The major reasons for the short shelf-life of pot herbs in the supply chain are wilting, yellowing and mould. Coriander has been recognised as the most problematic herb in terms of shelf-life and appearance by the British Herb Traders Association.

Yellowing occurs in coriander leaves for two reasons. Firstly, a flowering stem induces leaf senescence. Secondly, leaves themselves age. Both processes are included in the concept of 'harvesting window': this is the time period when the plant has reached a marketable size and leaf senescence has not yet started to spoil the appearance of the herb. The longer the harvesting window, the longer can the herb be displayed in pots or harvested from the field. We suggest that the current short harvesting window of coriander could be overcome by introduction of so-called 'leafy' varieties, because in Britain varieties of a 'fruit' group are traditionally cultivated.

Coriandrum sativum (Apiaceae) is an annual herb, which has been cultivated since ancient times in many countries both for fruits[2] (as a spice/herbal medicine) and for leaves as a vegetable (Ivanova and Stoletova, 1990). The dual use of coriander resulted in selection, by those who saved seed and grew coriander year-on-year, of varieties according to their ontogenetic features – varieties that were better at producing fruits and others that were better for harvesting leaves. During the vegetative stage plants produce from 1 to 15 leaves in a basal rosette. At the onset of flowering, the leaves in the basal rosette are completely developed and shortly after they senesce. Thus, varieties spontaneously selected for fruit production have few leaves in the rosette (1-4) and flower early. The flowering stem appears 43-55 days from sowing (Stoletova, 1931; Diederichsen, 1996). Varieties spontaneously selected for vegetable use are characterised by high production of leaves in a basal rosette (5-15) and late flowering, with the

[2] We use the term 'fruit' rather than 'seed' as coriander produces multi-seeded fruits.

flowering stem produced 66-76 days from sowing (Ivanova, 1966; Alborishvili, 1984; Diederichsen, 1996). Thus, 'leafy' varieties of coriander have two potential benefits compared to 'fruit' varieties for UK herb growers: firstly, the appearance of the 'leafy' varieties is better than that of the 'fruit' varieties as the 'leafy' varieties look more luxuriant and, secondly, the harvesting window of the 'leafy' varieties is longer than that of the 'fruit' varieties, as the rosettes live longer.

Coriander producers in the UK have not, as yet, benefited from the advantages of 'leafy' varieties, primarily because they have not been systematically evaluated for growth habit and flavour in the context of production and marketing in the UK. The UK industry has not taken the risk of growing 'leafy' varieties in preference to the better-known 'fruit' varieties, nor have they determined whether shelf-life might be improved.

Shelf life is, at least in part, a function of plant water relations. Wilting occurs during the marketing of pot-grown coriander because watering is labour consuming and is not applied in supermarkets. Efforts to reduce wilting have been concentrated around sophisticated post-harvest packaging (Flowers, Bashtanova, Svoboda, 2007): little or no research has been conducted on pre-harvest treatment, which might help pot herbs deal with drought stress on a retailer's shelf (Flowers, Bashtanova, Svoboda, 2007). Interestingly, it is known that many crops can benefit from a short period of drought: it makes plants tougher, more compact, with better marketing properties and improves water use efficiency (Shackel et al., 1997; Stoll et al., 2000). In protected horticulture, an effective way to impose a water deficit is to induce 'physiological drought' with saline irrigation (Yeo et al., 2000). Thus we investigated whether addition of salt to the nutrient solution improved coriander's weak appearance and shelf-life. In a previous study we found that high concentrations of salts (sodium chloride and sodium sulphate) were damaging; i.e. plants were short, leaves were small with brown necrotic edges. Subsequently, in this project, we tested low concentrations of sodium sulphate (6 and 12.5 mM) as it is less toxic for plants than sodium chloride.

In this project we investigated 'leafy' coriander varieties for pot and field growers and recommend growth conditions, which improve the appearance and shelf-life of coriander.

Materials and methods

a) Initial sourcing of varieties

Fruits of 48 'leafy' varieties of coriander were obtained from the N. I. Vavilov Research Institute of Plant Industry (VIR), Russia. The coriander collection in VIR contains 347 accessions from all over the world, and is enormously rich in Caucasian and Asian varieties (Fig. 2), which were mostly used for this study. Findings are documented in the VIR Herbarium, which is, along with the unique VIR Library, a valuable source of information. For simplicity, all accessions of the VIR collection of coriander are referred to here as 'varieties'. A better description would be 'genotypes taken into cultivation' because the collection contains a mixture of ecotypes, breeding lines and cultivars.

Fig. 2. Coriander diversity in Asia.

Left: A. Davydova collected a 'leafy' variety in Kazakhstan in 1975.

Right: N. Vavilov collected an extreme 'fruit' variety, which possesses only one basal leaf, in Afghanistan in 1924. Note the huge difference in plant height and leaf size, as both samples are mounted on A3 paper sheet.

Permission from VIR should be requested to copy these images for any other purpose than this report.

Varieties were selected from the VIR Collection based on either of two factors: number of leaves in the basal rosette or origin. Caucasian varieties (from Armenia, Azerbaijan, Daghestan and Georgia) were the first to be chosen; if a variety was mentioned (in the general literature, in the herbarium or by the curator of collection, Dr Olga Zvereva) to be exceptionally 'leafy' it was taken regardless of origin.

b) Seed propagation

Seeds were obtained from VIR in two portions: the first 28 varieties were obtained in May 2006 and the second 19 varieties – in January 2007 (due to a lack of sufficient quantity of seed in VIR in May). Correspondingly, plants were propagated in a greenhouse in the summers of 2006 and 2007: in a raised soil bed, 50 cm deep. Several varieties were propagated additionally in 3 L pots. The soil (in raised bed and in pots) was a mixture of John Innes Number 2 compost and sand (2 compost:1 sand; volume:volume) overlain by a layer (5 cm) of a mixture of peat and compost (in a 1:1 v:v mixture). The temperature range was 12–18 °C at night and 20–35 °C during the day.

To avoid cross-pollination, developed, but not yet flowering, umbels were covered with glassine bags (Fig. 3). Bags were removed at fruiting. [Note: outcrossing in non-covered coriander was reported to be 19% (Diederichsen, 1996); no inbreeding depression was found after three generations of selfing (Romanenko et al., 1992).]

Fig. 3. Propagation of coriander varieties in a greenhouse at the University of Sussex in raised soil bed.

Flowering plants are covered with glassine bags. Fruiting plants are uncovered.

c) Identifying 'leafy' varieties for the field industry

Identification of 'leafy' varieties for the field industry was based on summer trials in soil in a greenhouse (summer 2006 or 2007 depending on the date when seeds were obtained from VIR). Two characteristics were measured.

- **Time of bolting**, in days. This was measured as the time from seedlings emergence to the appearance of a flowering stem.
- **Number of leaves in the basal rosette**.

In addition, leaf area, strength of petioles and overall appearance of varieties was noted. All the information gathered is reported in the appendix A[3].

d) Identifying 'leafy' varieties for the pot industry

A preliminary selection of varieties suitable for the pot industry was performed in parallel with the trial described for the field industry (Section c, above).

Plants were grown in a greenhouse in pots in mixed peat substrates used in industry either in square 7 cm pots filled with substrate A or in round 10 cm diameter pots filled with substrate B. Nutrient solutions were the same as those currently used in industry. The range of temperature in the greenhouse was 10-18°C at night and 18-35 °C at day, depending on season. Additional light was provided for 12 h/day in November, December, January and February from sodium lamps. As soon as plants reached their harvestable stage, several vegetative and phenological characteristics were measured.

- **Plant height**, in cm.
- **Area of second leaf in rosette**, in mm^2. The second leaf, which was found to be the largest of the developed leaves in the rosette of all varieties, was taken ensuring that the sampling of leaf area was comparable across the varieties. Each leaf was scanned (ScanJet 6200C, Hewlett Packard,

[3] A picture of variety 202 was unavailable

USA) and the area of the leaf image estimated (Delta-T Scan software vs. 2.04).

- **Hypocotyl length,** in cm. This was measured separately from plant height to describe the appearance of the rosette: short hypocotyls ensure rosette stability; long hypocotyls make the whole rosette 'floppy'.
- **Plant dry weight,** in mg. This was measured as dry weight of green biomass (hypocotyls + petioles + leaves) after drying at 80° C for 5 days.
- **Appearance of petioles,** a subjective per pot characteristic was assessed visually. 'Floppy' was assigned to the pot if petioles drooped severely and touched a table; 'slightly floppy' - when some petioles were drooping, but not yet touching the table and 'upright' – when most of petioles in pot were upright.
- **Number of leaves in basal rosette at harvest.**
- **Number of leaves in basal rosette at bolting.** This shows if plants, starting from harvest, were preparing to bolt or continued to produce leaves. The latter would ensure a longer harvesting window.

After harvest, some pots were left in the same growth conditions; they were watered but not provided with nutrients and, as they aged, two important phenological characteristics were assessed.

- **Length of harvesting window**, in days was measured as the period from when the pot reached a saleable state (harvest) to the beginning of yellowing or bolting. A per pot characteristic.
- **Time of bolting**, in days. Was measured as the time from seedlings emergence to appearance of a flowering stem. A per pot characteristic.

e) Investigation of shelf-life

When plants reached their harvestable stage, five pots were sleeved in polyethylene sleeves used by industry and left without watering at 15 – 18 °C but in fluorescent light during the day-time - to simulate conditions on a supermarket shelf. Fresh weight of pots was measured every day and the day of wilting recorded for every pot.

f) Investigation on benefits of light and space availability

Plants were sown in medium round pots (diameter, 10 cm) either at high density of 36 fruits/pot (0.5 fruits/cm^2, as is normal practice in the industry) or at low density of 18 fruits/pot.

g) Investigation on benefits of adding sodium sulphate

Sodium sulphate was added to the nutrient solution to final concentrations of 6 and 12.5 mM Na_2SO_4. Treatment started when the first or second true leaf appeared in the rosette.

h) Measurement of osmotic pressure of leaf sap

The sap was extracted from frozen and then thawed leaves, centrifuged and collected into Eppendorf tubes. An automatic freezing-point micro-osmometer (Roebling, Germany) was used to measure the osmotic pressure.

i) Measurement of ion concentrations in leaves

Pieces of dried leaves were investigated under a scanning electron microscope (Leo S420, Cambridge, UK) fitted with electron probe microanalysis system (INCA Energy 200). Relative elemental spectra were obtained. A drop of nutrition solution with known elemental concentrations was dried, measured and used to convert relative values from elemental spectra to absolute values.

j) Measurement of transpiration

Transpiration was measured by infra-red gas analysis (CIRAS-1, PP Systems, UK).

k) Statistical analysis

Statistical analysis was carried out in Origin (OriginLab™). Normality of distribution of all measured characteristics (see description above) was tested (and found to be normal according to the Shapiro-Wilk test). Then a two sample independent t-test was carried out to check the significance of differences between controls and varieties.

For treatment experiments (light and spacing, nutrition with sodium sulphate) equality of variance was also tested by Fisher test (F-test) and found equal in all cases. Then two sample independent t-tests were carried out to find differences between control and treatment values.

Results and Discussion

Objective 1:

Search for the best 'leafy' varieties of coriander

a) Initial sourcing of varieties

The total number of varieties obtained from VIR was 48. They are listed in Table 1 under the same names as in the VIR database (http://www.vir.nw.ru/data/dbf.htm), and their origin is provided in parentheses.

Table 1. List of coriander varieties obtained from VIR (origin is given in brackets)

K-1 (Georgia)
K-3 (Azerbaijan)
K-4 (Kazakhstan)
K-5 (Daghestan)
K-6 (Azerbaijan)
K-9 (Armenia)
K-23 (Armenia)
K-34 (Ethiopia)
K-42 (Georgia)
K-43 (Georgia)
K-48 (VIR breeding line)
K-52 (Azerbaijan)
K-57 (Kazakhstan)
K-58 (Abhkazia republic of Georgia)
K-59 (Armenia)
K-60 (Armenia)
K-61 (Georgia)
K-62 (Georgia)
K-64 (Georgia)
K-66 (Armenia)
K-79 (Azerbaijan)
K-86 (Daghestan)
K-92 (Uzbekistan)
K-96 (Ethiopia)
K-100 (Belorussia)
K-101 (Kazakhstan)
K-103 (Armenia
K-111 (Abhkazia republic of Georgia)
K-114 (Abhkazia republic of Georgia)
K-115 (Abhkazia republic of Georgia)
K-116 (Abhkazia republic of Georgia)
K-123 (former Czechoslovakia)
K-126 (VIR breeding line)
K-129 (Armenia)
K-130 (Azerbaijan)
K-133 (Armenia)
K-142 (Syria)
K-148 (Adzharia republic of Georgia)
K-150 (Armenia)
K-153 (Uzbekistan)
K-157 (Adzharia republic of Georgia)
K-165 (Georgia)
K-166 (Georgia)

K-202 (Georgia)	K-213 (Armenia)	K-317 (Armenia)
K-203 (Georgia)	K-288 (Armenia)	

Most of the varieties chosen for study originated from the Caucasus region (Table 2). Information available showed that that this region is exceptionally rich in 'leafy' varieties and so all the accessions in the VIR collection from the Caucasus were selected, unless it was clearly stated in the literature or by the curator of the collection that a particular variety had been bred for 'fruit' production. In the initial proposal to HDC we supposed, based on a survey of the English literature, that varieties originating from near the Caspian Sea in Asia were also 'leafy'. However, a search in the VIR herbarium showed, there is a mixture of 'fruit' (the majority) and 'leafy' varieties, the latter mostly originating from Uzbekistan, Kazakhstan, Kyrgyzstan, Iran, Afghanistan, China and Mongolia (Fig. 2). Thus accessions from Asia were more carefully selected than accessions from the Caucasus, and only varieties known as 'leafy' were obtained from VIR. We also obtained 6 varieties of mixed origin, which were known from the literature to be 'leafy'.

Table 2. Origin of coriander varieties obtained from VIR

Georgia – 17 Armenia – 11 Azerbaijan – 5 Daghestan – 2	Kazakhstan – 4 Uzbekistan – 2 Syria – 1	Africa – 2 Europe – 2 VIR breeding lines – 2
Total from Caucasus: 35	Total from Asia: 7	Others: 6

b) Identifying 'leafy' varieties suitable for the <u>field industry</u>

Discussions at BHTA meetings in 2005-2006 showed that the most important developmental characteristic of coriander for field growers is time of bolting and the most important vegetative characteristics are number and size of leaves. Identification of promising 'leafy' varieties for the field industry was based mainly on a single summer trial in soil in a greenhouse (summer 2006 or 2007 depending on the date varieties were obtained from VIR), although consistency of important characteristics was checked during consecutive trials of these varieties in pots for pot industry. No contradictions were observed.

16 varieties were selected for the field industry (Table 3).

Table 3. List of coriander varieties recommended for field industry[4]

Late-bolting varieties	K-23, K-43, K-52, K-66, K-92, K-103, K-148, K-157, K-165
Medium-bolting varieties with exceptionally big leaves	K-60, K-62, K-101, K-150, K-213, K-288, K-317

As shown in Table 3, selected varieties were divided in two groups:

- **Late-bolting varieties**

  Bolting time is given for the greenhouse-grown plants. Bolting in the field, where summer temperatures are lower than in the greenhouse, will be prolonged. This group contains 9 varieties, which bolt in midsummer on the 35th day from germination or later. Variety K-43 was exceptionally tolerant to bolting. All varieties from this group have a usual leaf size, high number of leaves in the basal rosette, strong petioles and overall good appearance and colour. Pictures of these varieties and a short description of their characteristics, when grown in soil, can be found in the Appendix A.

- **Medium-bolting varieties with big leaves**

  This group is at risk of bolting between 25th-30th day from germination in hot summers. Thus for places where bolting might be an issue varieties

[4] Variety K- 59 is not recommended for the field industry. It is a medium bolting variety with ordinary leaf size. However, it looked a very promising variety for repeat cuts, with deep seated growth bud and long thick petioles. It could have potential for the domestic garden market.

should be trialled at the growing site. For spring and autumn sowing, these varieties are quite suitable. We recommend growing these varieties wherever possible, because they look lush and strong in soil and have remarkably big leaves and thick petioles. Pictures of these varieties and short descriptions of their characteristics, when grown in soil, can be found in the catalogue (see Appendix A).

Informal tasting of all varieties grown in soil resulted in the flavour descriptions given in Table 4. The taste characteristics listed in this Table should be viewed as preliminary and need further assessment in the conditions under which the plants would be grown.

Table 4. Taste of promising 'leafy' varieties of coriander

Tasting was performed once for plants growing in soil in a greenhouse at the University of Sussex and once for plants growing in pots in mixed peat substrate. Taste descriptions are therefore preliminary and not based on replicated trials. It should also be noted that the taste could be very different for field-grown coriander. Descriptive features of taste are given in the order of appearance during chewing.

Variety	Tasting in soil	Tasting in mixed peat substrate
K-4	Bug (characteristic for coriander herb), sweet, coriander, soft	Cashew nuts, sweet, coriander, soft
K-5	Sweet, coriander, grassy, UNPALATABLE	Dandelion bitterness, soft, nutty, UNPALATABLE
K-23	Mild coriander, bitter at the end, good texture	Sweet, misbalanced coriander
K-43	Slightly bitter, soapy, coriander, grassy at the end	Complex, coriander, pleasant

Variety	Tasting in soil	Tasting in mixed peat substrate
K-52	Grassy, seed, coriander at the end	Complex, coriander
K-57	Slightly bitter, coriander	Pleasant balanced coriander flavour
K-58	Slightly bitter, grassy, coriander at the end	Grassy, smooth finish, coriander, orange peel, lasts long
K-59	Bug (characteristic for coriander herb), sweet, coriander, soft, UNPALATABLE	Smooth, sweet, bug (characteristic for coriander herb), coriander
K-60	Seed, coriander, grassy at the end	Bug (characteristic for coriander herb), some bitterness, coriander
K-61	Grassy, coriander, slightly bitter, soapy, blunt, UNPALATABLE	Lemon-citrus note, grassy, coriander, soapy
K-62	Coriander, grassy, slightly bitter, soft	Coriander, grassy, slightly bitter, slightly sweet
K-64	Bug (characteristic for coriander herb) (disappears quickly), coriander	Bug (characteristic for coriander herb), coriander
K-66	Pleasant coriander, slightly bitter at the end	Sweet, orange peel, coriander
K-79	Coriander, slightly sweet, slightly bitter at the end	Coriander
K-92	Bug (characteristic for coriander	Coriander, slightly bitter

Variety	Tasting in soil	Tasting in mixed peat substrate
	herb), soapy, bitter, pronounced coriander	
K-101	Balanced coriander	Coriander
K-103	Coriander, sweet, no bitterness	Very flat coriander, almost none
K-114	Bitter, spicy, lots of coriander flavour, orange peel	Orangey, nice complex flavour, slightly bitter
K-115	Pleasant coriander, no spiciness	Very sweet, mild coriander, long lasting
K-116	Coriander, texture is too thin	Weak coriander flavour
K-123	Coriander, seed, no bitterness	Pleasant coriander
K-126	Pleasant strong coriander, slightly biter	Very juicy, coriander, slightly bitter
K-129	Pleasant coriander, slightly bitter, slightly orange	Sweet, bitter, sweet – misbalanced coriander
K-133	Not very aromatic, slight coriander	Bitter, grassy - misbalanced coriander
K-148	Slightly bitter, slight coriander	Strong, bitter, coriander
K-150	Sweet, slightly bitter, coriander	Sweet, reach in tones, coriander

Variety	Tasting in soil	Tasting in mixed peat substrate
K-153	Coriander, seed	Peasant coriander
K-157	Sweet, slightly spicy, good coriander	Coriander, sweet, bitter, mild texture with little spiciness
K-165	Slightly bitter, aromatic, good coriander	Slightly bitter, soft, good coriander
K-166	Sweet, carroty, slightly coriander	Good coriander, bitter at the end
K-202	Very grassy, slightly coriander	Soft, grassy, coriander
K-203	Mild, pleasant coriander, slightly bitter	Soft, spicy, orange peel, bitter, coriander
K-213	Bitter, soapy notes, smoky notes, coriander	Slightly bitter, coriander
K-288	Fresh, lemon zest, coriander at the end	Citrusey, coriander
K-317	Citrusey, good coriander	Sweet, coriander, texture is good

c) Preliminary identification of varieties for the pot industry

A preliminary selection of varieties for the pot industry was carried out in cooperation with industry. Vegetative characteristics such as visual appearance and number of leaves in the basal rosette of all 48 varieties sourced from VIR were assessed in soil-grown plants in a greenhouse (summer 2006 or 2007 depending on the date varieties were obtained from VIR). Later the most important developmental characteristic - time of bolting – was also noted. As a result 35 varieties were found promising and were taken for further trials in pots (see the catalogue, Appendix A); 13 were rejected. Within the rejected varieties there were several 'fruit' varieties (K-1, K-3, K-6, K-9, K-34, K-86, K-130 and K-142), miniature varieties (K-42 and K-111) and varieties that did not look like traditional varieties of coriander (K-96 and K-100); also variety K-48, which did not germinate. A list of varieties selected as promising for the pot industry is given in Table 5. It should be noted that although varieties K-79 and K-123 were designated as 'fruit' varieties, as they had a relatively low number of leaves in the basal rosette, they were taken for further trials due to their promising overall appearance.

Table 5. List of coriander varieties which were found promising for pot industry after the first trial in soil

K-4	K-116
K-5	K-123
K-23	K-126
K-43	K-129
K-52	K-133
K-57	K-148
K-58	K-150
K-59	K-153
K-60	K-157
K-61	K-165
K-62	K-166
K-64	K-202
K-66	K-203
K-79	K-213
K-92	K-288
K-101	K-317
K-103	
K-114	
K-115	

Total: 35

d) Propagation of varieties

Thirty five promising varieties of coriander were propagated for seeds to provide enough for several pot trials. Varieties K-202 and K-213 did not produce enough seeds and since they were obtained from VIR at the approach of the second summer, their multiplication could not be repeated. Varieties K-103, K-148 and K-157 produced lots of seeds, but with low germination, so that insufficient replication in trials meant that results using these varieties were excluded from this report.

e) Final identification of varieties for the pot industry

Thirty five promising varieties were tested in a greenhouse in pots (either in substrate A in 7 cm square pots or in substrate B in 10 cm round pots). Each variety was assessed for vegetative and phenological features; the characters assessed are listed in the Materials and Methods and the results detailed in Appendix B. Varieties currently used by the industry (var. *Americanum* and var. *Kashmir*) were included as controls.

Informal tasting of varieties was undertaken (see Table 4). Variety, K-5, was found consistently unpalatable both in soil and in pots and rejected on this basis.

Based on the whole complex of characteristics varieties K-5, K-101, K-114, K-115, K-116, K-123, K-129, K-150 and K-288 were also rejected after the first trial as they offered no improvement over, or were worse than, both controls.

If no firm decision could be made after a variety was first trialled, further trials were carried out. The aim was to test the most promising varieties three times (in winter, in summer and in spring-autumn) to cover seasonal differences in a greenhouse. Varieties K-202 and K-213 looked good 'leafy' varieties, but were trialled only once due to a shortage of seed.

It soon became clear that 'leafy' varieties of coriander could be divided in two clusters: varieties in the first cluster behaved evenly through the seasons; varieties in a second cluster were strongly affected by unfavourable season. Both industry controls were ascribed to the second cluster, as their appearance was strongly influenced by midsummer heat. They bolted so early that plants did not reach a saleable height and had small scorched leaves. Finally, based on the performance of 'leafy' varieties in different seasons, we divided them into three groups[5].

- **All season varieties**

  These were medium to late-bolting varieties. They performed evenly through the seasons, although there was some occasional scorching in summer or stretched floppy petioles in winter. Examples of these varieties

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[5] Varieties K-5, K-101, K-114, K-115, K-116, K-123, K-129, K-150, K-202, K-213 and K-288 were trialled only once, thus are not listed in examples, as it is difficult to ascribe them to a 'season' group.

are: K-23, K-43, K-52, K-58, K-66, K-92, K-133, K-148, K-153, K-165 and K-317.

Again, from these varieties we selected only the best, based on vegetative characteristics (stronger petioles, higher number of leaves in rosette and shorter hypocotyls) and with harvesting window longer than of controls (see Table 6 and appendix B).

- **Winter/ autumn/ spring varieties**

These varieties had a better appearance and harvesting window in cool seasons with short days than in warm or hot seasons. In summer, they had a short harvesting window due to bolting and were no better than controls *Kashmir* and *Americanum*, having either floppy stretched petioles or shortened petioles with small scorched leaves. Examples of winter/autumn/spring varieties are: *Americanum*, *Kashmir*, K-4, K-57, K-59, K-60, K-61, K-62, K-64, K-79 and K-126.

The use of such varieties may be justified if their appearance is better than of both controls in cool seasons. Varieties with stronger petioles, bigger leaves, higher number of leaves in the rosette and shorter hypocotyls were selected and recommended for use in winter/spring/autumn (see Table 6 and Appendix B). As the selected varieties have a higher number of leaves than controls in cool seasons, they also have a longer harvesting window (see Appendix B).

- **Summer varieties**

These are medium- to late-bolting varieties. In summer they have a longer harvesting window than *Americanum* and *Kashmir*. These varieties flourish in hot weather, have strong upright petioles and fully expanded non-scorched green leaves, giving them an advantage over both industry controls, which suffer in the summer (see above and Appendix B). In winter, 'summer varieties' such as K-103, K-157, K-166 and K-203 looked as poor as controls having stretched floppy petioles.

Thus, summer varieties with vegetative characteristics better than controls (stronger petioles, higher number of leaves in rosettes and shorter hypocotyls) are recommended for industry to use in hot seasons with long days (see Table 6 and Appendix B).

From 35 promising varieties, 15 were finally selected as they out-performed controls on appearance and harvesting window either in a favourable season, or all year round. Full explanations of decisions on all 35 promising varieties are provided in Appendix B. A list of varieties selected for the pot industry is given in Table 6.

Table 6. List of coriander varieties recommended for pot industry[6]

Summer varieties	K-103, K-157, K-202
Winter/spring/autumn varieties	K-4, K-60, K-61, K-64
All season varieties	K-23, K-43, K-58, K-66, K-92, K-133, K-165, K-317

f) Harvesting window of pot-grown 'leafy' varieties

The harvesting window is a very important characteristic of pot-grown coriander as it shows the time period over which plants are large enough to sell and yet leaf senescence has not yet started to spoil the appearance of the plants. The longer the harvesting window, the longer a harvest could be postponed, providing flexibility in the delivery to market.

The length of the harvesting window is limited by leaf senescence induced by bolting on the one hand and normal leaf ageing on the other. For late-bolting varieties, the harvesting window is usually limited by leaf ageing (see for example harvesting window of varieties K-23, K-43, K-66, K-92 and K-165 in Appendix B). For medium-bolting coriander varieties, the harvesting window in summer/late spring/early autumn is usually limited by bolting, and in winter by leaf ageing (see for example harvesting window of

[6] Variety K- 213 is not listed in the table, although it looked a promising 'leafy' variety, but not enough trials were performed due to seed shortage

Variety K- 202 is listed as a summer variety because it performed well in summer. No trials were performed in spring/winter/autumn, due to a seed shortage.

varieties *Americanum*, K-4, K-58, K-60, K-133 and K-317 in Appendix B). Early-bolting 'fruit' varieties were not analysed in this study except for the control *Kashmir*, which is a 'fruit' variety whose harvesting window was always limited by bolting (see Appendix B).

Between varieties, those finally selected were those that out-competed controls on harvesting window either in a favourable season or all year round. This is illustrated by Fig. 4. All varieties selected for the pot industry had 1 to 12 days longer harvesting window than the controls. This lengthening of the harvesting window was statistically significant for 'all-season' varieties and 'spring/winter/autumn' varieties. Statistical analysis was not performed for 'summer' varieties, because only one summer was available for trials. It should be noted that temperature buffering and light control in our experimental greenhouse could differ from large commercial greenhouses. Thus we recommend checking harvesting window of 'medium-bolting' varieties at the site of their production, as harvesting window depends on time of bolting, which in turn depends on light and temperature.

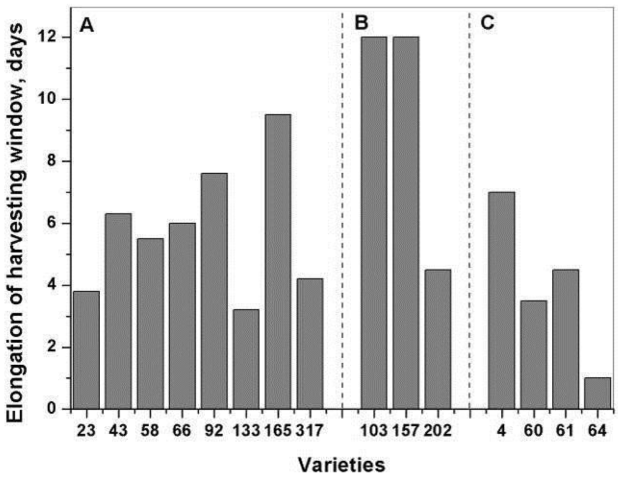


Fig. 4. Harvesting window of 15 coriander varieties finally selected for the pot industry.

Harvesting window was measured as the period from when a pot reached a saleable state (harvest) to the beginning of yellowing or bolting.

Harvesting window of controls (*Americanum* and *Kashmir*) were averaged and assigned as zero. Increases were statistically significant for all-season varieties and spring/winter/autumn varieties. Statistical analysis was not performed for summer varieties, as there was only one summer available for trials.

A: all-season varieties (harvesting window was compared to controls in every season)

B: spring/autumn/winter varieties (harvesting window was compared to controls in every season except summer)

C: summer varieties (harvesting window was compared to controls in summer)

g) Investigation of shelf-life of pot grown 'leafy' varieties

Shelf-life is a very important characteristic for pot-grown coriander as it shows how long a herb will survive without watering on a supermarket shelf.

The shelf-life of coriander plants was tested by packaging three varieties and both controls in polyethylene sleeves routinely used by the industry. Fresh weight was measured every day, and the day wilting was first apparent recorded for every pot.

For this experiment three 'leafy' varieties with very different appearance were chosen: K-4, K-43, and K-60. K-60 had very big leaves and a loose plant arrangement in the pot, so high transpiration was expected (see Appendix B). K-4 was chosen because its appearance was very similar to both controls. It had almost the same leaf size and a loose plant arrangement in the pot (see Appendix B) so its transpiration was expected to be less than that of K-60 and similar to that of the controls. K-43 was chosen because it looked potentially more resistant to drought than both controls: it had a similar leaf size, but a compact ball-shape appearance in pots (see Appendix B).

No statistically significant differences were found in water loss from pots with different varieties grown on different peat mixtures. The only exception was K-43 in substrate A in square pots (Fig 5), which on days 2 and 3 had significantly higher pot fresh weight than other varieties. However it started wilting on the same day as the other varieties. Thus, we did not find differences in water loss between the few coriander genotypes tested. This suggests that, without watering, wilting of coriander on a supermarket shelf will start on the third or fourth day whatever variety is used.

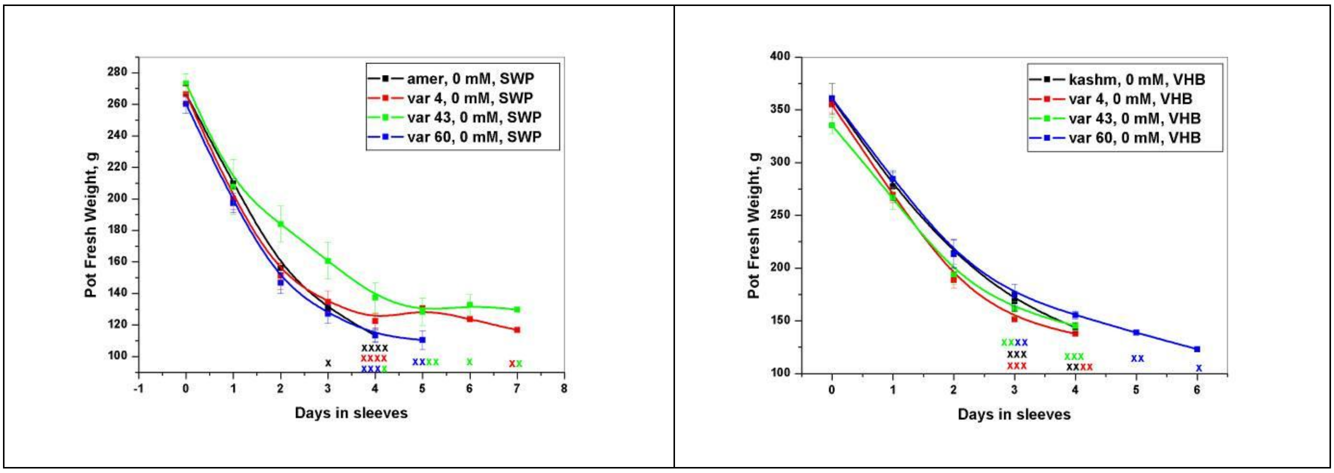


Fig. 5. Shelf-life of selected 'leafy' varieties of coriander.

Water loss was measured as pot fresh weight. Each value is a mean of five pots ± SE. 'X' indicates wilting of each pot.

Left: water loss from sleeved pots in varieties *Americanum* (black), K-4 (red), K-43 (green) and K-60 (blue) grown in substrate A in square pots.

Right: water loss from sleeved pots in varieties *Kashmir* (black), K-4 (red), K-43 (green) and K-60 (blue) grown in substrate B in round pots.

Conclusions for Objective 1

16 'leafy' coriander varieties suitable for field growers and 15 'leafy' coriander varieties for the pot industry have been identified. There was an overlap of 9 varieties in the total of 31 selected.

The large number of varieties selected for field growers provides them with a range of opportunities. If bolting is a major concern, varieties from the 'late-bolting' group should be sown. If high biomass is desirable and bolting is a minor issue, varieties from the 'medium-bolting group with big leaves' should be sown.

Pot growers are also provided with a range of opportunities. Several varieties are resistant to summer heat and long days ('summer varieties'); several other varieties are resistant to extremes of temperature in the UK and day length fluctuations ('all season varieties').

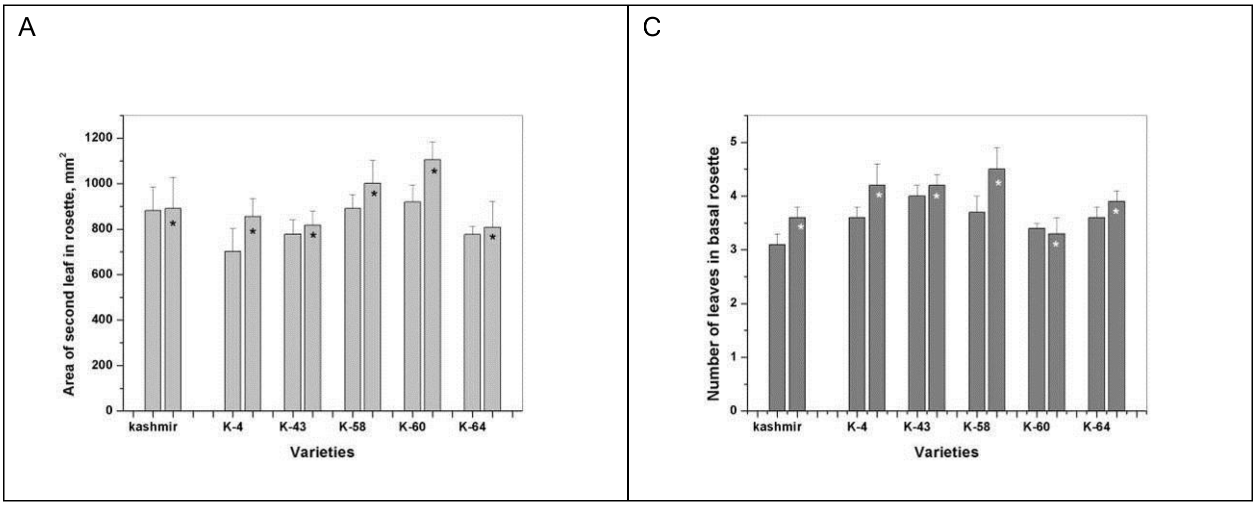
All the varieties selected for the pot industry performed better than those currently used on appearance (petiole strength, number of leaves in rosette and hypocotyl length) and harvesting window. Many out-competed controls on leaf size and biomass. No differences were observed in shelf-life between coriander genotypes.

Objective 2:

Identifying optimal growth conditions for the pot grown 'leafy' varieties

a) Improvement of appearance due to light and space availability

It became clear early in the project that coriander was very sensitive to light and/or space availability. If germination in pots was, for some reason, lower than in the industry control (normally sown at 36 fruits/pot in 10 cm round pots i.e. 0.5 fruits/cm^2 or 20 fruits/pot in 7 cm square pots i.e. 0.4 fruits/cm^2) the smaller number of plants per pot had an improved final appearance, with the plants looking stronger than those sown at a higher density. We therefore investigated the effects of light and



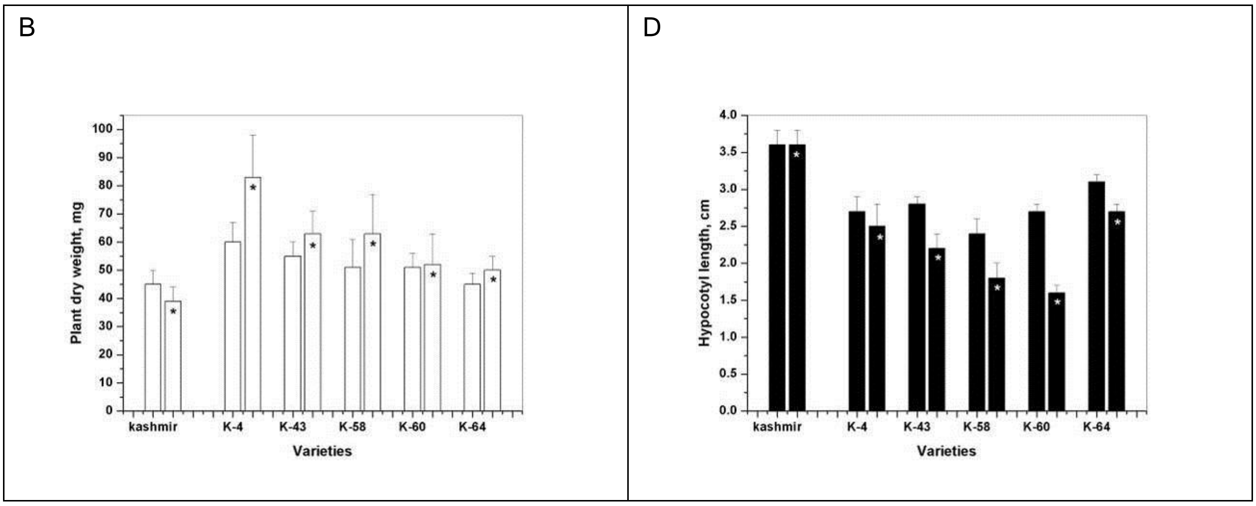


Fig. 6.Changes in appearances of several coriander varieties in response to lower sowing density.

Varieties *Kashmir*, K-4, K-43, K-58, K-60 and K-64 were sown in 10 cm round pots either at 36 fruits/pot or at 18 fruits/pot (indicated with *).

A: second leaf area. Increase was statistically significant only in variety K-60.

B: plant dry weight. Increase was statistically significant only in variety K-4.

C: number of leaves in rosette. Increase was statistically significant in *Kashmir*, K-4 and K-58.

D: hypocotyl length. Decrease was statistically significant in K-43, K-58, K-60 and K-64.

space availability on development of the leaf rosette. Several 'leafy' varieties already chosen for the pot industry (K-4, K-43, K-58, K-60 and K-64) and the fruit variety *Kashmir*. Varieties were sown in 10 cm round pots in substrate B either at high density of 36 fruits/pot (normal practice) or at low density of 18 fruits/pot. We found that leaf area, plant dry weight and number of leaves in the rosette (Fig. 6 A, B, C) increased in all 'leafy' varieties when sown at the lower density. The leaf rosette appeared to develop better when plants were spaced out, although statistically significant increases were observed only in some cases (see Fig 6).

At the lower sowing density, hypocotyl elongation rate was lower than in pots planted at the higher density. Hypocotyl length was significantly lower in all 'leafy' varieties (K-43, K-58, K-60 and K-64) at low density compared with high density pots, except for

K-4, where although lower, the difference was not significant (Fig. 6 D). Hypocotyl length is a very important characteristic for coriander: short hypocotyls ensure rosette stability, whereas long hypocotyls make the rosette unstable and droopy. Interestingly, *Kashmir* had no reaction to sowing density: its hypocotyls did not become shorter in low density pots. It is likely that the large size of the cotyledons in *Kashmir* (Fig. 7) shades the hypocotyls, irrespective of sowing density. Shading promotes hypocotyl elongation and thus *Kashmir* grown in pots is likely to have long hypocotyls and a droopy rosette.

Fig. 7. *Kashmir* and variety K-61 at the stage of cotyledons .

Note large broad cotyledons of Kashmir (left pot) in comparison with slender cotyledons of K-61 (right pot).

The difference in the area of specific leaves between different sowing densities might become more pronounced the younger the leaf because the younger leaves develop in more shaded environments in the more densely planted pots than in those planted at low density. Consequently, we analysed the areas of first, second and third leaves in pots planted at low and high densities. We found that, indeed, the leaf area in well-spaced plants was greater the younger the leaf: three significant increases between treatments were found for third leaves (*Kashmir*, K-43, K-58), one for second leaves (K-60), but none for first leaves (Fig. 8).

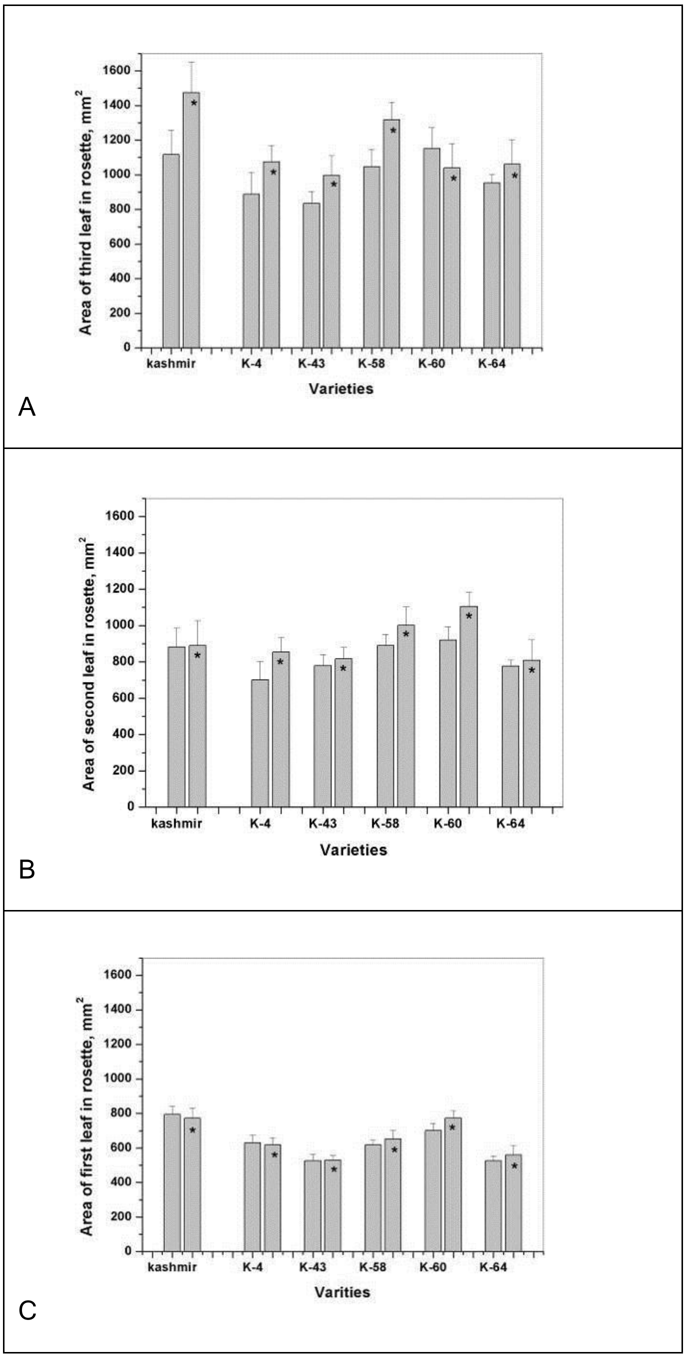


Fig. 8. Changes in leaf area of several coriander varieties in response to lower sowing density.

Varieties *Kashmir*, K-4, K-43, K-58, K-60 and K-64 were sown in 10 cm round pots either at 36 fruits/pot or at 18 fruits/pot (indicated with *).

Area of first, second and third leaf in rosette was measured.

A: third leaf. Increases were statistically significant in *Kashmir*, K-43 and K-58

B: second leaf. Increase was statistically significant only in K-60

C: first leaf. No statistically significant increases.

b) Elongation of shelf-life and improvement of appearance in pot grown 'leafy' varieties: treatment with sodium sulphate

- **Elongation of shelf-life**

A preliminary experiment on the effect of low concentrations of sodium sulphate (Glauber's salt) in the nutrient solution was performed using varieties *Kashmir*, *Americanum*, K-52 and K-62. The concentrations of Na_2SO_4 trialled were 6 and 12.5 mM. Varieties *Americanum* and K-52, grown in substrate A, were treated with Na_2SO_4 at the stage of the first true leaf and *Kashmir* and K-62, grown in substrate B, were treated at the stage of the second true leaf. Sodium sulphate dramatically improved the shelf life of coriander with the higher salt concentration delaying wilting of pot in sleeves longer than the lower salt concentration (Table 7; note only two pots for each treatment were sleeved for this preliminary experiment, so comparison of drought resistance between varieties could not be drawn from the results).

We also found that yellowing of cotyledons occurred earlier for plants where Na_2SO_4 was applied at the first leaf stage compared with plants treated at the second leaf stage. Thus in further experiments we applied salt at the stage of second true leaf.

Table 7. Effect of sodium sulphate in the nutrient solution on wilting of coriander varieties.

The start of wilting is given as the number of days from the day pot was put in a polyethylene sleeve to the day the plants started to wilt.

	0 Na_2SO_4	**6 mM Na_2SO_4**	**12.5 mM Na_2SO_4**
Americanum	8 days	9 days	10 days
K-52	7 days	8 days	9 days
Kashmir	5 days	6 days	7 days
K-62	6 days	7 days	8 days

As the preliminary results showed a positive effect of Glauber's salt on coriander shelf-life, we investigated the statistical significance of the effect using varieties K-4, K-

43, K-60, *Kashmir* and *Americanum.* The Na_2SO_4 was given at the stage of the second true leaf and the concentration was 12.5 mM. Varieties K-4, K-43, K-60 were sown in two different substrates (substrate A in 7 cm square pots and substrate B in 10 cm round pots) currently used by industry. *Americanum* and *Kashmir* were used as controls.

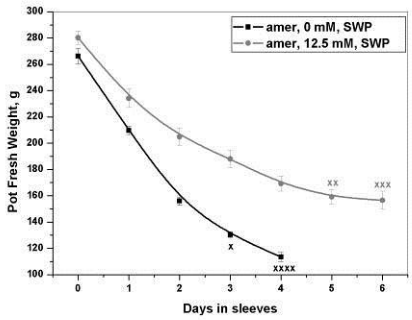
This detailed investigation showed that improvement was dramatic (Fig 9). All pots treated with Na_2SO_4 lost water much more slowly than non-treated pots, thus wilted much later. Shelf-life increased by 33-170% (1-7 days) depending on substrate and variety (Fig. 10). The effect was significant for all varieties, grown in either substrate, indicating a clear positive effect of sodium sulphate on shelf-life. However, the extent of the delay in wilting varied with both substrate and variety, indicating that further work may be useful to clarify the effect of the substrate on longevity.

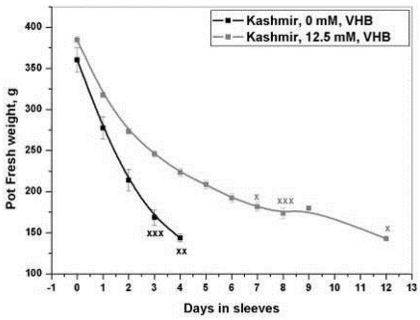
The greatest increase in longevity was seen with K-60 in substrate A. K60 started to wilt 7 days later than plants in non-treated pots (Fig. 10). For the other varieties, illustrated in Fig. 10, K-4 started to wilt 4 days later in both substrates (data shown only for the substrate B); *Kashmir* started to wilt 4 days later; *Americanum,* 3 days later; K-60, 3 days later in substrate B (data not shown); K-43, 2 days later in substrate A and one day later in substrate B (data not shown).

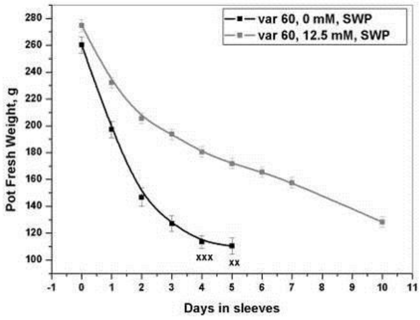
Fig 9. Improvement of shelf-life of pot-grown coriander by treatment with sodium sulphate.

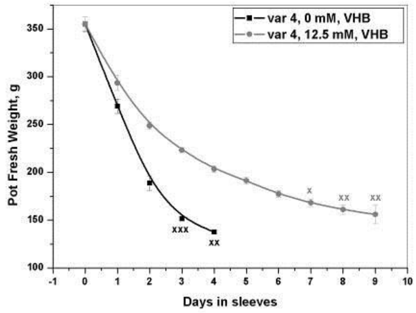
Upper picture: varieties K-4, K-43, K-60 and *Kashmir* were treated with nutrient solution containing 12.5 mM Na_2SO_4 (four rows on the right) or with nutrient solution only (four rows on the left).

Lower picture: same varieties on the fifth day without watering.









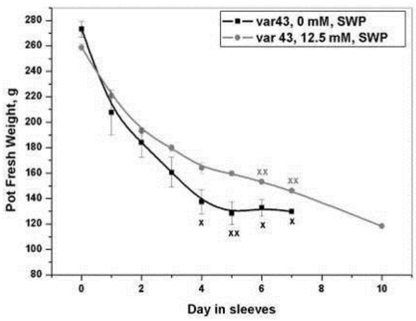


Fig 10. Improvement of shelf-life of pot-grown coriander by sodium sulphate. Detailed view. Examples.

First row: variety *Americanum* grown in substrate A.

Left cell: water loss from pots treated (grey) and non-treated (black) with 12.5 mM Na_2SO_4. Water loss was measured as pot fresh weight. Each value is a mean of five pots ± SE. 'X' indicates wilting of each pot.

Central cell: as wilting started non-treated pots were taken out of sleeves and photographed.

Right cell: treated pots were also taken out from sleeves and photographed on the same day as non-treated

Second row: variety *Kashmir* grown in substrate B. Cells arranged the same way.

Third row: variety K-60 grown in substrate A. Cells arranged the same way.

Forth row: variety K-4 grown in substrate B. Cells arranged the same way.

Fifth row: variety K-43 grown in substrate A. Cells arranged the same way.

- **Improvement in appearance of petioles**

The addition of Na_2SO_4 to the nutrient solution improved the characteristics of the petioles (Table 8). The petioles were assessed visually: 'floppy' was assigned to a pot if petioles drooped severely (see, for example, pictures of *Kashmir* and *Americanum* on the left in Appendix B); 'slightly floppy' - when some petioles in a pot were drooping, but many were upright (see for example pictures of K-133 and K-92 on the right in Appendix B; and 'upright' – when most of the petioles in a pot were upright (see for example pictures of K-133 and K-157 on the left in Appendix B).

It is clear from Table 8 that improvement of the appearance of petioles, even in the best 'leafy' varieties, was possible. Without added Na_2SO_4 , 7 cases out of 10 were floppy or slightly floppy, and only 3 were upright. When treated with Na_2SO_4 the appearance of the petioles improved dramatically: none was floppy, 3 were slightly floppy and 7 appeared upright.

Table 8. Positive effect of minor concentration of sodium sulphate on petioles appearance

Key: 'floppy' - petioles drooped severely;

'slightly floppy' – some petioles were droopy, but not severely and many were upright;

'upright' – when most of the petioles in a pot were upright.

Each cell in the table represents assessment of 3-6 pots. Each row represents different replicas.

	0 Na_2SO_4	12.5 mM Na_2SO_4
Kashmir	Floppy	**Upright**
Kashmir	Floppy	Slightly floppy
Americanum	Slightly floppy	**Upright**
Americanum	Slightly floppy	**Upright**
K-4	Slightly floppy	**Upright**
K-4	**Upright**	**Upright**
K-43	**Upright**	**Upright**
K-43	Slightly floppy	**Upright**

K-52	**Upright**	**Upright**
K-60	Floppy	Slightly floppy
K-60	Slightly floppy	**Upright**
K-62	Floppy	Slightly floppy

- **Other minor changes of appearance**

Low concentrations of Na_2SO_4 were used because it was considered unlikely that they would spoil the appearance of the coriander. We confirmed this using varieties K-4, K-43, K-52, K-60 and K-62 and controls *Kashmir* and *Americanum*. Hypocotyl length, plant height, leaf area and number of leaves in a rosette were measured. Most differences were statistically insignificant, with some minor differences relating to substrates.

- **Research on the mechanism of sodium sulphate action**

Investigating the underlying mechanism behind the extension of shelf-life and improvement in wilting in coriander plants grown with Na_2SO_4 was not in the remit of this project. However, having found such a remarkable improvement, we investigated whether osmotic pressure (OP) in the leaf might change. The OP was measured in sap obtained from frozen leaves of varieties *Americanum*, *Kashmir*, K-52 and K-62 grown with (12.5 mM) and without Na_2SO_4 (controls). *Americanum* and K-52 were grown in substrate A and *Kashmir* and K-62 were grown in substrate B. There was an 8 – 30% increase in osmotic pressure for varieties grown with added Na_2SO_4 (Table 9). Differences were statistically significant for plants grown in the substrate B.

Table 9. Osmotic potential of leaf sap of four coriander varieties treated with sodium sulphate.

The sap was extracted using three frozen and then thawed leaves. A freezing-point micro-osmometer was used to measure the osmotic potential. Five replicas were measured for each treatment. Results are given as mean ± SE.

Variety/ Growth substrate	Osmotic potential, mOsmol		Increase in osmotic potential of leaf sap
	0 (control)	12.5 mM Na_2SO_4	
Kashmir/ Substrate B	456 ± 18	588 ± 7	29%
K-62/ Substrate B	530 ± 8	603 ± 5	14%
K-52 Substrate A	515 ± 6	557 ± 5	8 %

In order to check which ions might be responsible for the increases in osmotic pressure, dried leaves of varieties *Americanum*, *Kashmir*, K-52 and K-62 grown without (controls) and with 12.5 mM Na_2SO_4 were analysed by electron probe microanalysis. Three relative elemental spectra were obtained from four leaf samples from different plants, making a total of twelve spectra per variety. A drop of nutrient solution with known elemental concentrations was dried, measured and used to convert counts from elemental spectra for Na, S, K, Ca, Mg, Cl to absolute quantities.

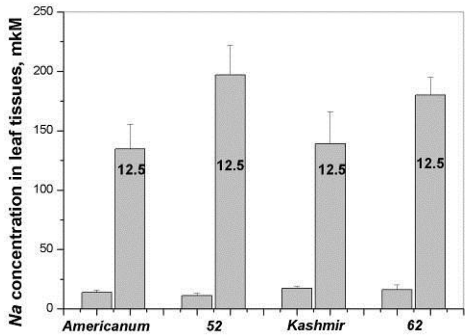
As expected, concentrations of sodium and sulphur increased in all varieties (Fig. 11 A, B) on treatment with Na_2SO_4. Thus, the ions Na^+ and SO_4^{2-} were responsible for the increase in osmotic pressure in leaves grown with the addition of Na_2SO_4. Usually an increase in Na^+ concentration in plants is accompanied by a decrease in K^+, but this did not happen in the case of coriander. No corresponding changes of K were found (Fig. 11 D), but instead a decrease in Mg was consistently observed in all varieties (Fig. 11 C). Thus, for some reason influx of Na into coriander leaves was balanced by a net decrease in Mg concentration, rather than K. Changes in the elemental balance in coriander leaves did not correlate with changes in leaf colour, size or appearance, as no such changes were observed (see above); the plants did not show any symptoms of Mg deficiency. Overall it should be noted that changes in Na, S and Mg content in coriander leaf grown with and without Na_2SO_4 were negligible as far as the nutritional value was concerned.

As water loss from pots decreased when Na_2SO_4 was added to the nutrient solution we assumed that transpiration rate of plants during day and/or night would have changed.

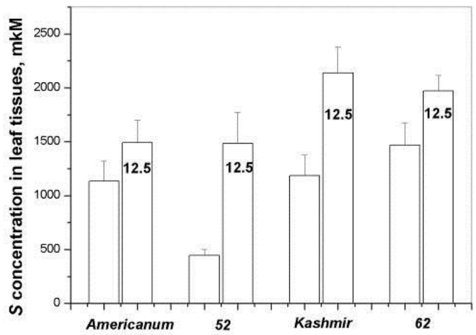
We measured day-time transpiration in varieties *Americanum*, *Kashmir*, K-52 and K-62 grown with addition of 6 and 12.5 mM of Na_2SO_4. We did not, however, find any changes in transpiration rate between controls and plants treated with Na_2SO_4 (Fig. 12). Although there were some decreases and increases, they were not statistically significant, except decreases in transpiration in *Americanum* at 6 mM (Fig. 12 A) and in K-52 at 12.5 mM Na_2SO_4 (Fig. 12 B). But even these statistically significant changes did not form a pattern in a series of concentrations or across the varieties. We concluded that there was no change of transpiration rate during the day. It leaves the question of any change of night-time transpiration rate, which remains un-investigated,.

Thus, the mechanism of action of Na_2SO_4 is yet to be understood. All we know is that the osmotic pressure of treated leaves is higher than of non-treated leaves and this is likely to be associated with the influx of Na^+ and SO_4^{2-} into the leaf. We suggest that a change in osmotic pressure or the concentration of specific ions might trigger hydraulic and/or chemical signals, which somehow improve water retention in the plants. It is likely that plant transpiration is reduced at night, as, given the lack of effect on day-time water loss, it is the only way to decrease overall water loss from the plants.

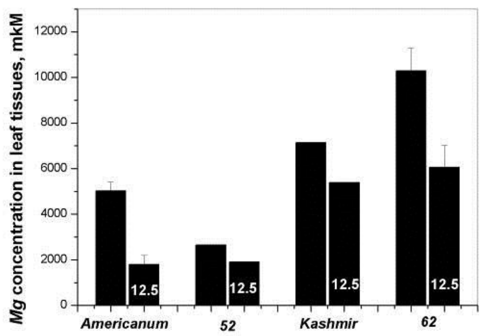
A



B



C



D

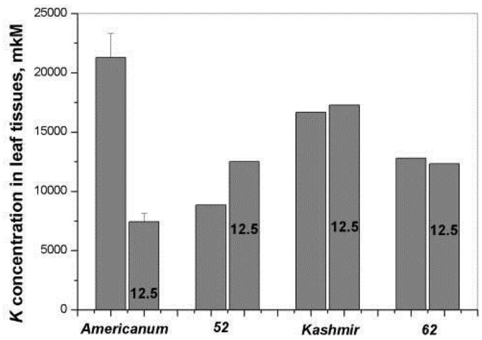


Fig. 11.Changes in elemental concentrations in four coriander varieties treated with sodium sulphate.

Concentrations of sodium (A), sulphur (B), magnesium (C) and potassium (D) in leaves were obtained using scanning electron microscope fitted with electron probe microanalysis.

Plants were treated with 0 (control) or 12.5 mM sodium sulphate (indicated with '12.5'). Four leaf pieces from different plants were taken; three relative elemental spectra were obtained from each piece.

For all statistically significant changes error bars (± SE) are shown.

Changes in calcium and chlorine (data not shown) were similar to potassium (fig. 11 D) and did not show any consistent pattern of between the four varieties tested.

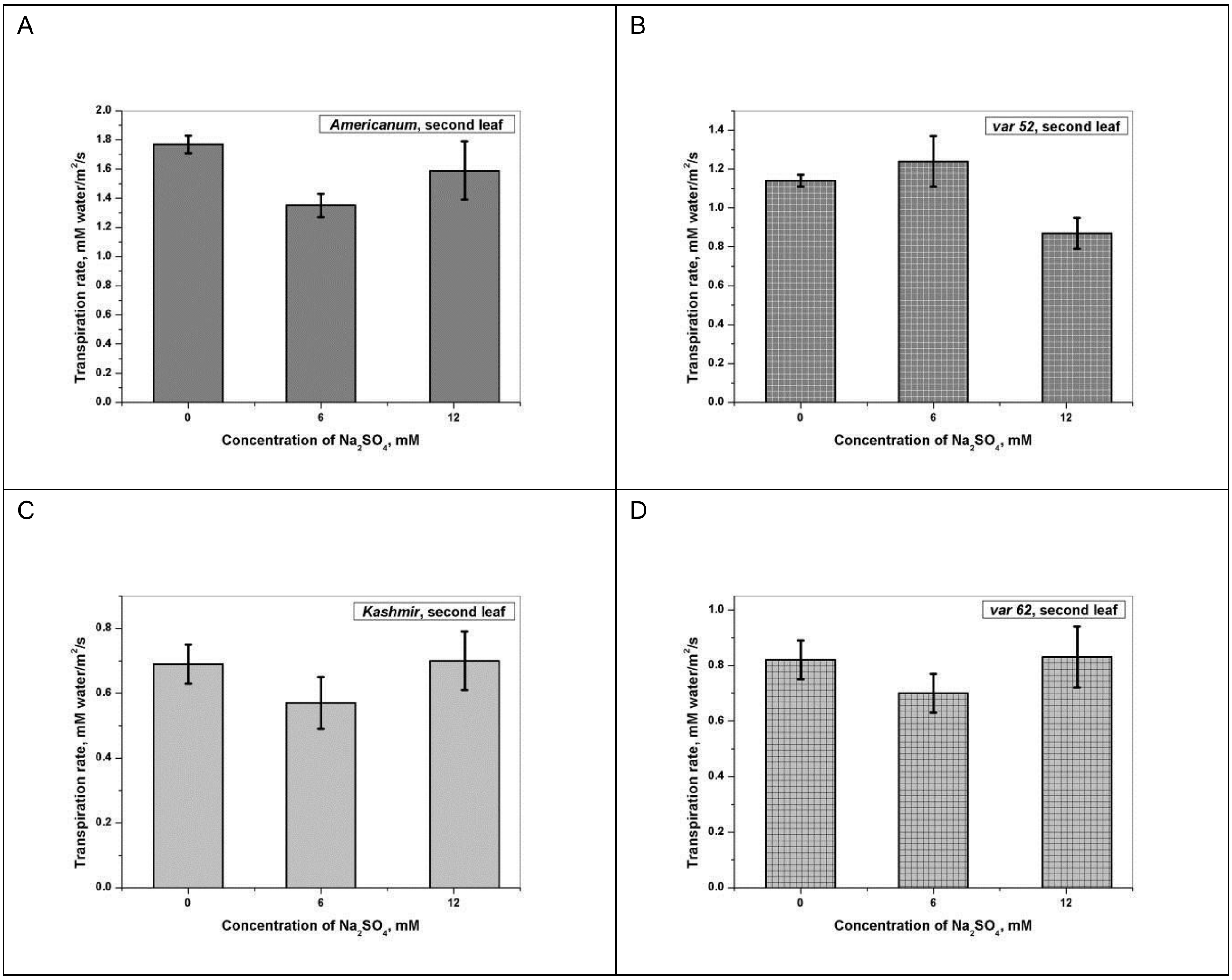

A
Americanum, second leaf
Transpiration rate, mM water/m2/s
Concentration of Na2SO4, mM
B
var 52, second leaf
Transpiration rate, mM water/m2/s
Concentration of Na2SO4, mM
C
Kashmir, second leaf
Transpiration rate, mM water/m2/s
Concentration of Na2SO4, mM
D
var 62, second leaf
Transpiration rate, mM water/m2/s
Concentration of Na2SO4, mM

Fig. 12. Transpiration intensity during the day-time in four coriander varieties treated with sodium sulphate.

Transpiration of plants grown with 0, 6 and 12.5 mM sodium sulphate was measured by infra-red gas analysis using the second fully-expanded leaf. Each bar represents mean ± SE of 6 replicas obtained from different leaves; 30 records were taken for each leaf.

A: transpiration rate of variety *Americanum* grown in substrate A. Decrease at 6 mM is statistically significant.

B: same for K-52 grown in substrate A. Decrease at 12.5 mM is statistically significant.

C: same for *Kashmir* grown in substrate B. No statistically significant changes.

D: same for K-62 grown in substrate B. No statistically significant changes.

Conclusions for Objective 2

Growth conditions which improve the appearance and shelf-life of pot-grown coriander have been developed.

Space and light availability is crucial for rosette development: when sown at lower density plants have shorter hypocotyls, higher number of leaves in rosettes, higher plant biomass and bigger leaves.

We recommend a change in practice to plant 'leafy' varieties of coriander at two fold lower density than currently used by the industry.

The addition of minor concentrations of sodium sulphate dramatically improves the shelf-life and decreases 'flopping' in pot grown coriander.

We recommend applying sodium sulphate at a concentration of 1.6 g/l when the second true leaf in the rosette appears. Some adjustments of concentration and time of application might be needed due to differences of growth conditions in greenhouses.

Overall conclusions

- We identified 16 'leafy' varieties of coriander suitable for field growing from a collection of 347 accessions at N. I. Vavilov Research Institute of Plant Industry (VIR), Russia.
- Identification of these 16 varieties provides field-growers with a range of opportunities. If bolting is a major concern varieties from a 'late-bolting' group should be sown. If high biomass is desirable and bolting is a minor issue varieties from a 'medium-bolting' group should be sown.
- We selected 15 'leafy' coriander varieties that are highly suitable for growing in pots. Of these 15 varieties, 9 overlapped those selected for field growing. All these varieties were better than those currently used by pot growers as judged by their appearance (strength of petioles, number of leaves in the rosette and hypocotyl length) and harvesting window. Many out-competed the varieties in current use on leaf size and biomass.
- The selection of 15 varieties provides pot growers with a range of opportunities. Several varieties are resistant to summer heat in greenhouses and long days ('summer varieties'); several other varieties are resistant to fluctuations in temperature and day length ('all season varieties'); other varieties have exceptionally big leaves and biomass; others show reduced 'flopping' of petioles.
- Treatments are reported that improve the development of the leaf rosette, strong petioles and shelf-life.
    - For improved growth and rosette development, pot-grown coriander should be sown at a lower density than is current practice. For the pot industry, density could be decreased two fold without a loss in appearance of the product.
    - For longer shelf-life and stronger petioles pot-grown plants should be treated with 1.6 g/l sodium sulphate in nutrient solution applied when the second true leaf in the rosette appears.
- The mechanism of action of sodium sulphate is yet to be understood.

Technology transfer

- Regular meetings (four each year) have been held with industry representatives.
- Publication of results in a scientific journal is in preparation.
- An HDC fact sheet for growers should HDC is planned.

References

Alborishvili C (1984). Promising varieties of vegetable herbs [in Russ Eng. Abstr.] *Naucho-Technicheskii Bulleten' VIR im. Vavilova* 141, 53

Chennel A, Tomkins B, Franz P (1999). Storage of culinary herbs. A report for Rural Industries Research and Development Corporation, Kingston, Australia

Diederichsen A (1996). Coriander. Promoting the conservation and use of underutilised and neglected crops. 3. Institute of Plant Genetics and Crop Plant Research, Gaterslkeben/International Plant Genetic Resources Institute, Rome.

Flowers T, Bashtanova U, Svoboda K (2007). Herbs: Pre- and post-harvest factors affecting shelf-life, flavour, yield and quality. A review. Horticulture Development Council, UK

Ivanova K (1966). Spicy vegetables of Transcuacasicus [in Russ Eng. Abstr.] *Trudy po prikladnoi botanike, geetike i selekcii* 28, 178

Ivanova K, Stoletova E (1990). The history of culture and intraspecific taxonomy of Coriander sativum L. [in Russ Eng. Abstr.]. *Sbornik nauchnyh trudov po prikladnoi botanike, genetike i selekcii* 133, 26

Romanenko LG, Nevkrytaja NV, Kuznecova E (1992). Self fertility in coriander [in Russ]. Selekcia i Semenovodstvo, Moskva, USSR

Shackel KA, Lampinen B, Southwick S et al. (1997). Deficit irrigation in Prunes: getting more with less. HortSci 32, 705

Stoletova E (1931). Coriander [in Russ] Vsesojuznaya akademiya sel'skochozayistvennyh nauk im. Lenina. Izdanie instituta rastenievodstva, Leningrad

Stoll M, Loveys B, Dry P (2000). Hormonal changes induced by partial rootzone drying in irrigated grapevine. *Journal of Experimental Botany* 51, 1627

Yeo AR, Koyama ML, Chinta S, Flowers T (2000). Salt tolerance at the whole plant level. In: Cherry (ed) Plant Tolerance to Abiotic Stresses in Agriculture: Role of Genetic Enginering 3, 107. Kluwer, Holland.

Appendices

Appendix A: Promising 'leafy' varieties of *Coriandrum sativum* L. sourced from N.I. Vavilov Research Institute of Plant Industry (VIR), Russia.

In this appendix pictures of one-month-old plants grown in a soil-bed in a glasshouse are provided; vegetative and phenological characteristics are featured and an explanation of the basis for the decision on suitability for the field industry is provided.

Appendix B: Description of vegetative and phenological characteristics of coriander varieties preliminarily selected for pot growers and explanations of the basis of the final decision .