

**Identification and Management of Factors Limiting  
Hybrid Carrot Seed Production in Australia**

by

5.  
Cameron Spurr

B.Agr.Sc. (Hons.) University of Tasmania

Submitted in fulfilment of the requirements for the degree of  
Doctor of Philosophy

University of Tasmania

August 2003

## Disclaimer

This thesis contains no material which has been accepted for the award of any other degree or diploma in any other University and to the best of my knowledge, contains no copy or paraphrase of material previously published or written by any other person except where due reference is made in the text.

## Authority of Access

This thesis is not to be made available for loan or copying for two years following the date this statement was signed. Following this time the thesis may be made available for loan and limited copying in accordance with the Copyright Act 1968.



C. J. Spurr

August, 2003

## Summary

Worldwide, carrot seed production is a highly dynamic industry, with vegetable breeders contracting the production of proprietary varieties to areas where technology and climate combine to give the most reliable yields of high quality seed. Australia has had a significant share of the world market for carrot seed production since 1984, servicing customers in Asia, Europe and the United States. Since the mid 1990s, requirements for increased quality and reliability of production, coupled with improvements in the production standards of other carrot seed exporters, have threatened Australia's market share. The failure of a significant number of Australian crops to meet the current minimum production standard of 85% seed germination required by export markets has been the major issue faced by the industry during this period. In addition, producers have experienced difficulty in consistently achieving satisfactory yields of seed of some hybrid varieties.

The present study was undertaken to address both of the issues facing Australian producers, with an emphasis on achieving improvements in the production of seed of European hybrid carrot varieties. Preliminary work established that the problems of low germination and unreliable yields were largely unrelated, leading to two research themes based on cause and management of low germination and unreliable seed yield.

Low germination of Australian seed lots was closely correlated to the occurrence of seeds without embryos or with embryos exhibiting extensive physical damage. Surveys of carrot fields and caging trials in South Australia and Tasmania established that both conditions resulted from feeding of the endemic insect, *Nysius vinitor* Bergroth (Hemiptera: Lygaeidae) on developing carrot seeds. Adult *N. vinitor* were found to infest carrot seed crops in a series of migratory flights from shortly before flowering until harvest. In Tasmania evidence was collected that suggested that a significant proportion of migrants originate from nearby areas of weedy host species. During peak periods of migration populations of up to 17 insects per carrot plant were observed. Field based

caging trials showed that loss of germination due to *N. vinitor* feeding could occur from flowering through to harvest. For individual male sterile plants, daily reductions in seed germination of 0.04 to 0.11% per insect were observed during this period.

Because of the need to respond quickly to *N. vinitor* infestation to minimise germination loss, work was undertaken to develop protocols for monitoring the insect in carrot seed crops. In trial plots, sticky traps detected migrations of *N. vinitor* into carrot fields, with the number of insects caught closely correlated to average population densities on the plants. In commercial crops *N. vinitor* population densities were non-randomly distributed across the fields, with gradients associated with the prevailing wind directions during the periods of migration. Thus, the positioning of the sticky traps was shown to be important for reliable detection of *N. vinitor* as well as accurate estimation of population size.

The issue of unreliable seed yield was examined in two hybrid crosses, No. 22, a 3-way (F1 male sterile line) Nantes hybrid with brown anther cytoplasmic male sterility (CMS) and WO030, an F1 Nantes hybrid with petaloid CMS. Two alternative hypotheses; source limitation (assimilate) and pollination limitation, were tested to explain the occurrence of low seed yields. Shading, umbel removal and leaf trimming treatments applied to both hybrids over two seasons did not significantly affect seed yield, seed size or seed quality. Supplemental hand pollination treatments increased seed yield by up to 284%, providing evidence that seed yield was strongly limited by inadequate pollination in No. 22, and to a lesser extent in WO030. In both hybrids, pollination was restricted by variable pollen viability at anthesis, low pollen longevity under field conditions and low rates of pollen transfer to the male sterile line.

Commercial hybrid carrot seed production is based on the strip method of hybrid seed production in which rows of the pollinator line are alternated with the male sterile line. Within the strip method, varying the ratio of pollinator and male sterile lines between 1:4 and 4:4 and distance between adjacent male beds between 2.4 to 7.2m had no effect on pollination or seed yields of No. 22. Surveys of insect pollinator visitation, pollen loads

and foraging patterns explained these results. Honeybees, *Apis mellifera ligustica* Linnaeus (Hymenoptera: Apidae) and two Dipteran species *Calliphora ruficornis* Macquart (Diptera: Calliphoridae) and *Eristalis tenax* Linnaeus (Diptera: Syrphidae) effected most pollination in carrot seed plots. All three species showed a strong tendency for directional foraging within a single row of plants, thereby restricting the opportunities for pollination of the male sterile line. These findings suggest that the strip method of production may be incompatible with the foraging behaviour of some important pollinators of hybrid carrots and hence the attainment of optimum seed yields in some varieties.

This thesis identifies significant opportunities for improvement of the quality and reliability of hybrid carrot seed production in Australia. Management protocols for *N. vinitor* derived from the research have contributed to an increase in the percentage of commercial carrot seed crops achieving the germination standard required for export from below 70% prior to 2000 to 100% in 2003. Studies of yield variability identify inadequate pollination as a contributing factor. Efforts to improve pollen viability and pollen transfer in commercial production may contribute to greater reliability of hybrid seed yields.

## **Acknowledgements**

I would like to sincerely thank my supervisors, Drs. Neville Mendham and Philip Brown for their support and guidance throughout this project and enthusiasm to help at all times.

It has been my pleasure to work with South Pacific Seeds (SPS) on this project. The enthusiasm and practical support I have received has been nothing short of exceptional. In particular, I would like to make special mention of Craig Garland, Production Manager for SPS, Tasmania, Max Dalrymple, Production Manager for SPS, South Australia, Kylie Fulton, formerly of SPS, South Australia and John Hall, SPS, Griffith, who were closely involved with the project from the beginning. I would also like to thank the SPS field staff in Tasmania, South Australia and New Zealand and SPS's growers, who were always willing to help out with field trials.

In the early stages of this project I was able to undertake a study tour of vegetable seed production in the Pacific North West of the United States and attend the 28<sup>th</sup> International Carrot Conference in Washington State through the financial support of Horticulture Australia and SPS. I am particularly indebted to Phil Hancock, Managing Director of SPS, who organised many of the contacts and provided the introductions that paved my way on this excellent learning experience.

Throughout this project I have received considerable help from the staff at the School of Agricultural Science and TIAR. I am especially grateful for the advice and expertise I have received from Lou Hanslow, Phil Andrews, Bill Peterson, Dr. Geoff Allen, Dr. David Ratkowski and Dr Owen Seeman.

Finally I would like to thank my family, extended family and friends for their help and encouragement and especially my wife, Diane, who endured this project with patience and love and provided the practical and emotional support that was needed.

# Table of Contents

<b>SUMMARY</b>	<b>III</b>
<b>ACKNOWLEDGEMENTS</b>	<b>VI</b>
<b>CHAPTER 1</b>	<b>1</b>
<b>GENERAL INTRODUCTION</b>	
1.1 - THE CARROT SEED INDUSTRY	1
Worldwide Carrot Seed Production	1
The Australian Carrot Seed Industry	2
1.2 - REPRODUCTIVE BIOLOGY OF THE CARROT	4
Initiation of Flowering – Juvenility, Vernalisation and Photoperiodic Requirements	4
Flowering and Pollination	5
The Carrot Seed	8
Hybrid Systems	9
1.3 – CULTURAL PRACTICES FOR CARROT SEED PRODUCTION	11
1.4 - RESEARCH IMPETUS AND PROJECT FOCUS	14
1.5 – OUTLINE OF THESIS STRUCTURE	14

## **CHAPTER 2** **16**

### **GENERAL MATERIALS AND METHODS**

2.1 - PLANT MATERIAL	16
2.2 - FIELD EXPERIMENTS	17
2.3 - GLASSHOUSE EXPERIMENTS	22
2.4 - POLLEN COLLECTION, STORAGE AND VIABILITY TESTING	23
2.5 - EXAMINATION OF POLLEN DEPOSITION ON THE STIGMAS OF MALE STERILE FLOWERS.	23
2.6 - SEED HARVESTING, PREPARATION AND STORAGE.	24
2.7 - SEED YIELD ASSESSMENT	24
2.8 - SEED GERMINATION ASSESSMENT	25
2.9 - SEED EMBRYO ASSESSMENT	25
2.10 – STATISTICAL ANALYSIS	26

## **CHAPTER 3** **27**

### **PRELIMINARY STUDIES OF YIELD AND GERMINATION OF CARROT SEED IN AUSTRALIA AND NEW ZEALAND**

3.1 – LITERATURE REVIEW	27
Poor Germination of Carrot Seed	28



Low Hybrid Seed Yields	31
Conclusion	32
 3.2 - MATERIALS AND METHODS	 34
Trial Sites	34
Cultural Practices and Trial Design	34
Seed Harvests	37
Seed Yield and Quality Assessment	37
Statistical Analysis	38
 3.3 - RESULTS	 39
Seed Yield	39
Germination	41
 3.4 - DISCUSSION	 48

---

## **CHAPTER 4** **52**

### **FEEDING DAMAGE AND MANAGEMENT OF *NYSIUS VINITOR* BERGROTH (HEMIPTERA: LYGAEIDAE) IN RELATION TO CARROT SEED YIELD AND QUALITY**

4.1 - LITERATURE REVIEW	53
<i>Nysius</i> (Dallas) in Australia and New Zealand	53
The Biology of Australian <i>Nysius</i>	56
Migration and Dispersal of Australian <i>Nysius</i>	60
Crop Damage	65
Management Options	67
Conclusion	68
 4.2 - MATERIALS AND METHODS	 70
Survey of Seed Feeding Insect in Carrot Seed Crops	70
Seed Yield and Quality Effects from Exposure of Carrot Plants to <i>N. vinitor</i> During	
Mid Seed Development	71
Seasonal Prevalence of <i>N. vinitor</i> in Carrot Seed Crops	72

The Relationship of Timing and Level of Adult <i>N. vinitor</i> Infestation to the Yield and Quality of the Seed Produced	75
Monitoring of <i>N. vinitor</i> Populations in Carrot Seed Crops	79
 4.3 – RESULTS	 81
Survey of Seed Feeding Insects in Carrot Seed Crops.	81
Seed Yield and Quality Effects of Post Fertilisation Exposure to <i>N. vinitor</i>	83
Seasonal Prevalence of <i>N. vinitor</i> in Carrot Seed Crops	84
Seed Yield and Quality with Respect to the Level and Timing of Infestation of Adult <i>N. vinitor</i>	91
Monitoring of <i>N. vinitor</i> in Carrot Seed Crops	95
 4.4 - DISCUSSION	 99

---

## **CHAPTER 5** **105**

### **TECHNIQUES FOR HANDLING, STORING AND TESTING THE GERMINATION CAPACITY OF CARROT POLLEN**

5.1 – LITERATURE REVIEW	105
The Pollen Grain	105
Pollen Viability and Longevity	107
Pollen Storage	111
Pollen Viability Testing	113
Conclusion	118
 5.2 – MATERIALS AND METHODS	 119
Examination of the Nuclear Number of Carrot Pollen at Anthesis	119
Evaluation of Pollen Viability Tests For Use with Carrot Pollen	119
Validation of the FCR Test for Routine Use	122
The Effects of Desiccation and Rehydration on Pollen Viability	122
The Effect of Storage Temperature on Pollen Longevity	123

5.3 - RESULTS	125
Examination of the Nuclear Number of Carrot Pollen at Anthesis	125
Evaluation of Viability Tests for Use with Carrot Pollen	125
Validation of the FCR Test for Routine Use	127
The Effect of Desiccation and Rehydration Conditions on Pollen Viability	129
The Effect of Storage Temperature on Pollen Longevity	131
5.4 - DISCUSSION	132

---

## **CHAPTER 6** **135**

### **SOME LIMITING FACTORS FOR SEED SET IN HYBRID CARROT SEED CROPS**

6.1 - LITERATURE REVIEW	135
Female Flower Fertility	136
Pollination and Fertilisation	137
Factors Affecting Seed Set After Fertilisation	142
Conclusion	144
6.2-MATERIALS AND METHODS	145
Plant Material and Environmental Conditions	145
Modification of Resource Availability for Seed Development	146
Pollination Experiments	148
Pollen Viability Experiments	151
6.3 - RESULTS	155
Modification of Resource Availability for Seed Development	155
Pollination Experiments	159
Pollen Viability Experiments	170
6.4 - DISCUSSION	178

---

**CHAPTER 7****184****POLLINATOR FORAGING PATTERNS AND PARENT LINE ARRANGEMENT IN RELATION TO  
HYBRID SEED YIELD**

7.1 - LITERATURE REVIEW	184
Pollen Vectors in Carrot	184
Insect Pollinators of Carrot Seed Crops	185
Recommendations for Pollination of Carrot Seed Crops	187
Factors Affecting Pollinator Visitation Rates to Carrot Seed Crops	188
Pollinator Foraging Patterns	189
The Effects of Parent Line Arrangement on Hybrid Seed Yields	193
Conclusion	194
 7.2 - MATERIALS AND METHODS	 196
Plant Material and Climatic Conditions	196
The Effects of Parent Line Arrangement on Pollination and Seed Yield	197
Pollination Vector Studies	199
Data Analysis	202
 7.3 - RESULTS	 203
The Effects of Parent Line Arrangement on Pollination and Seed Yield	203
Pollination Vector Studies	206
 7.4 - DISCUSSION	 217

---

**CHAPTER 8****223****GENERAL DISCUSSION**

PROJECT OVERVIEW	223
KEY FINDINGS	224

NYSIUS VINITOR IN RELATION TO CARROT SEED GERMINATION	225
POLLINATION AND POLLEN VIABILITY IN HYBRID CARROT SEED CROPS	229
Pollination	229
Pollen viability	234
RECOMMENDED MANAGEMENT PRACTICES FOR IMPROVED SEED GERMINATION AND YIELDS FROM AUSTRALIAN CARROT SEED CROPS	237
RECOMMENDATIONS FOR FURTHER RESEARCH	239
<b><u>REFERENCES</u></b>	<b><u>242</u></b>

# Chapter 1

## General Introduction

*This chapter is written in three sections. The first provides a brief historical background to the Australian carrot seed industry within the context of the worldwide industry. The status of the Australian industry during the late 1990s, at the time of commencement of this project, and the development of the problems that were its genesis are described. The second section explains the concepts of reproductive development and seed production that are fundamental to the research that was undertaken. The final section of the chapter describes the focus and broad objectives of the research and outlines the structuring of this thesis.*

---

### **1.1 - The Carrot Seed Industry**

#### **Worldwide Carrot Seed Production**

Worldwide, in excess of 3000 ha of carrot seed crops are produced annually (Schreiber and Ritchie, 1995; Simon, 2000). A large proportion of this is contracted or 'in house' production of proprietary varieties for vegetable breeding companies. The United States (Washington, Oregon, Northern California and Idaho) and southern France currently dominate the seed production industry. Other significant producers include Australia, New Zealand, Italy, Israel, Japan and Chile. Based on the figures provided by Schreiber and Ritchie (1995) and Simon (2000) hybrid seed accounts for approximately 60% of carrot seed production.