

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

A STUDY OF QUANTITATIVE GENETICS
ON SOME CHARACTERS OF THE
MEADOWFOAM PLANT
(*LIMNANTHES ALBA BENTH.*)

A thesis presented in partial fulfilment of the requirements for the
Master of Applied Science degree in Plant Science at
Massey University

Chin Lui *Foo*
March 1998

ABSTRACT

The meadowfoam plant is a moisture-loving native of the west coast of the North American continent near the borders of USA and Canada. It has recently stirred great interest in the chemical oil industry due to the potential of its seed oil to substitute for sperm whale oil. Due to the relative lack of published literature on this plant, an experiment was planned to study the quantitative genetics of some of its characters.

Thirty-six half-sib families were planted and the following characters were examined: plant height; diameter; uprightness; intensity of redness on branches and its distribution; leaf shape; period to first flower; seed set; mature seed retained; degree of seed shattering; and thousand-seed mass. Factor analysis was also performed on the flowering pattern of the plants.

Results indicated that all characters were heritable in the broad-sense, and all but two characters (diameter and degree of seed shatter) had significantly heritable narrow-sense heritabilities. The amount of genetic variability present in this species is also very high. Plant improvement methods based on selection are therefore recommended. Predictions on genetic advance show that the characters plant height, seed retention, leaf shape, and red intensity and distribution on branches showed greatest promise for rapid improvement.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisor, Dr. Ian L. Gordon, for both illuminating and expanding my mind through the duration of this work. His patient guidance has built up a strong foundation for me upon which academic confidence has been built. He has excelled in both roles as mentor and friend through my years at Massey.

The technical staff at Massey has also contributed greatly to lighten my load in this project. Many thanks to Mr. Mark Osborne for the initial field preparation work; and also to Mr. Robert Southward for his field advice, and his contribution of time and dedicated efforts in seed and data collection.

My friends have also contributed significantly in this project, in both physical effort and for providing camaraderie which has maintained my stress at 'healthy' levels. They are: *Chan Weng Kong*, *Chuah Seong Kee*, *Tan Gaik Seong*, *Tan Seong Ho*, *Teoh Ee Ling* (Ms.), and *Yang Ming-Huang*. In addition, *Yang Ming-Huang* gets special notice for being a very good friend at Massey for 5½ years.

This work would also not be possible without the emotional and financial support from my family, with whom weekly contact has lent me great support.

I also wish to thank the Singapore Government for the temporary suspension of my scholarship bond, and the facilitated provision of necessary documents to allow my continued sojourn in New Zealand.

The financial assistance provided by the Massey Masterate Scholarship and the Turners and Growers Research Grant is gratefully acknowledged.

Table of Contents

<i>Abstract</i>	<i>i</i>
<i>Acknowledgements</i>	<i>ii</i>
<i>Table of contents</i>	<i>iii</i>
<i>List of figures</i>	<i>vii</i>
<i>List of tables</i>	<i>viii</i>
<i>List of appendices</i>	<i>ix</i>

1.0 INTRODUCTION

<i>1.1 Historical background to the meadowfoam plant</i>	<i>1</i>
<i>1.1 Use of biometrics in plant improvement</i>	<i>2</i>

2.0 MEADOWFOAM REVIEW

<i>2.1 Limnanthes systematics</i>	<i>3</i>
<i>2.2 Habitat and life cycle</i>	<i>7</i>
<i>2.3 Unique characteristics of Limnanthes seed oil</i>	<i>8</i>
<i>2.4 Novel oil extraction and content determination methods</i>	<i>12</i>
<i>2.5 Industrial uses of Limnanthes oil</i>	<i>12</i>
<i>2.6 Oil content</i>	<i>14</i>
<i>2.7 Potential use as animal feed</i>	<i>14</i>
<i>2.8 The choice of L. alba as a candidate for oil yield domestication</i>	<i>15</i>
<i>2.9 Comparisons between L. alba and L. douglasii</i>	<i>16</i>
<i>2.10 Cultural notes on growing Limnanthes alba</i>	<i>18</i>

2.10.1 Temperature	18
2.10.2 Secondary dormancy following warm temperature treatment	19
2.10.3 Breaking of dormancy	20
2.10.4 Flowering period and seed yield	20
2.10.5 Drainage and seed yield	20
2.10.6 Photosynthesis during maturity	21
2.10.7 Pollination	21
2.10.8 Fertiliser and seed yield	22
2.10.9 Weed control	25
2.10.10 Harvesting and seed yield	26
2.10.11 Phytomass and seed yield	27
2.10.12 Seed set efficiency	28
<i>2.11 Future directions</i>	29
2.11.1 Towards autogamous plants	30
2.11.2 Male sterility in meadowfoam	33

3.0 BIOMETRICAL REVIEW

<i>3.1 Introduction to quantitative genetics</i>	35
<i>3.2 Heritability</i>	38
<i>3.3 Estimating heritability</i>	39
<i>3.4 The variance of heritability</i>	42

4.0 MATERIALS AND METHODS

4.1 *The Experiment*

4.1.1 Inference population	46
4.1.2 Field design	46
4.1.3 Cultural practices	
4.1.3.1 Field preparation	48
4.1.3.2 Irrigation	48
4.1.3.3 Pest Control	49
4.1.3.4 Weed Control	49

4.2 *Characters measured*

4.2.1 Plant size and posture	49
4.2.2 Leaf shape	50
4.2.3 Redness intensity and distribution on branches	50
4.2.4 Date of first flowering	52
4.2.5 Pattern of flowering	52
4.2.6 Number of fertilised ovules	52
4.2.7 Number of seeds retained at maturity per flower head	53
4.2.8 Degree of seed shattering	53
4.2.9 Average 1000-seed mass	53

4.3 *Data analysis*

4.3.1 Experimental design and statistical model	54
4.3.2 Analysis of variance	55
4.3.3 Estimating heritability	55
4.3.4 Estimating the genetic coefficient, g_k	56
4.3.5 Analysing pattern of flowering	57

5.0 RESULTS AND DISCUSSION

<i>5.1 Identifying the 'pattern of flowering' factors for further analysis</i>	60
<i>5.2 Analysis of variance</i>	
5.2.1 Character means	65
5.2.2 Coefficients of variance	65
5.2.3 F-test results of the mean squares	74
5.2.4 Variance components	77
<i>5.3 Genetic influence</i>	
5.3.1 Within-plot variance	85
5.3.2 Heritabilities	87
5.3.3 Heritability variance components	91
<i>5.4 Overall discussion</i>	
5.4.1 Significance of heritability	95
5.4.2 Elucidation of flowering pattern through factor interpretation	95
5.4.3 The use of half-sibs in the estimation of narrow-sense heritability	102
5.4.4 Heritability in plant breeding decision-making	103
5.4.5 Expected genetic advance	104
5.4.6 Character consideration in future meadowfoam improvement programs	107

6.0 CONCLUSIONS	109
------------------------	-----

7.0 REFERENCES	111
-----------------------	-----

List of Figures

Figure 1	Natural distribution of <i>Limnanthes sp.</i>	5
Figure 2	Floral morphology of outcrossing <i>Limnanthes alba</i> and autogamous <i>L. floccosa</i>	32
Figure 3	Layout of the experimental field	47
Figure 4	Leaf shape scores	50
Figure 5	Colour score for redness	51
Figure 6	Variance component η^2 pie-charts	
Figure 7a	Plot of Factor2*Factor3	68
Figure 7b	Plot of Factor2*Factor4	69
Figure 7c	Plot of Factor3*Factor4	70

List of Tables

Table 1	Typical Composition of long chain fatty acid sources	11
Table 2	Amino acids in meadowfoam protein	15
Table 3	Germinating rates of <i>Limnanthes alba</i> at various temperatures	18
Table 4	Sum of cross products of genetic frequency and mean genotypic value	42
Table 5	Expectations of mean squares	54
Table 6	Award of points to standardised coefficients of factor analysis	58
Table 7	Award of points to values of structure matrix	59
Table 8	Determining the strength of factor against input sources	59
Table 9	Proportion of variance accounted for by each factor	61
Table 10	Factor pattern (Structure matrix)	62
Table 11	Standardised Score Coefficients	63
Table 12	Interpretation of factors	64
Table 13	Means and coefficients of variance for all characters	72
Table 13a	Means and coefficients of variance for factors	72
Table 14	Means by population	73
Table 15	Mean scores across all plants in the 10 weeks of flowering surveyed	78
Table 16	F-test significance of the mean squares	81
Table 17	Variance components	84
Table 18	Genetic coefficients and total proportion (%) of genetic influence in variance	92
Table 19	Significance of heritabilities at various levels	94
Table 20	Narrow-sense heritability variance components	99
Table 20a	Broad-sense heritability variance components	100
Table 21	Genetic advance and its components	106

1.0 INTRODUCTION

1.1 Historical background to the meadowfoam plant

The meadowfoam plant (*Limnanthes alba*) has gained considerable interest due to the potential of myriad uses of its seed oil where industrial applications are concerned. It was first identified in the 1950s when the U. S. Department of Agriculture (USDA) conducted an extensive program to search for new crops amongst untested plants. The ideal new crop-plant candidate should fill a present or anticipated need and its usefulness should not compete with existing crops. This was done in part to alleviate the problems of massive surpluses of major food crops every year. Potential plant products and applications sought include cellulosic compounds for the pulp and paper industry, proteins for animal feed and industrial use, useful polysaccharides other than starch, natural toxins useful for pest and pathogen control, alkaloids, waxes, and unique vegetable oils (Earle *et al.*, 1959).

In the search for new plant products, oils receive special attention primarily because it has higher economic value per unit volume than proteins or fibres. It also has many applications in industry, the prime vehicle for value-addedness to a natural product. Industrial trends indicate increasing usage of oils as chemical intermediates in industry. It was of no surprise then, that greater interest was stirred when *Limnanthes* oil was named in 1971 as the most promising substitute for sperm whale oil (*Limnanthes* oil, together with *Crambe abyssinica* and *Simmondsia chinensis* (jojoba) oils were considered as possible substitutes for sperm whale oil (Hagemann and Rothfus, 1981)); after all sperm whale products were banned in 1969 when the Endangered Species Conservation Act was passed in the USA (Jolliff, *et al.*, 1981).

If successfully domesticated, demand for *Limnanthes* oil is expected to be strong, given that the US alone consumed 50 million pounds of sperm whale oil annually until 1972 for use in cosmetics, waxes, pharmaceuticals, lubricants, etc. Before attention was focused on its seed oil potential, the only cultivated species of *Limnanthes* was *L. douglasii* for its ornamental flowers (Purdy and Craig, 1987). The short life cycle and genetic variability suggests great potential for rapid crop improvement. The *Limnanthes* plants appeared to be efficient in the processing of raw matter and also produced a high ratio of seed to vegetative matter.

The seed oils are valuable because more than 95% of the fatty acids contain 20 or 22 C-chains which are mainly unsaturated at the 5C but sometimes at the 13C. This makes them suitable for a wide plethora of industrial uses such as waxes, lubricants, detergents, and plasticizers. Natural *Limnanthes* oil can be made into a liquid wax similar to jojoba oil, and when fully hydrogenated, a high quality solid wax about as hard as carnauba and candelilla waxes can be obtained. The oil content of *Limnanthes* seeds vary from 25-33% but fatty acid content of the C₂₀:1 type can be as high as 52-77% of the total seed oil (Higgins *et al.*, 1971).

1.2 Use of biometrics in plant improvement

Quantitative genetics deals with those traits which are expressed in a continuous spectrum rather than discrete classes. Most economic traits relating to yield fall within this definition. The manipulation of variation caused by genetic factors through breeding and selection forms the backbone of most plant breeding programs. The objective of plant breeding research is to enable better manipulation of these variations so that the desired qualities are realised.