Moisture Adsorption and Spoilage Characteristics of Pea Under Adverse Storage Conditions

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ABSTRACT

Field pea is the most produced and exported pulse crop in Canada, and makes a major contribution to Western Canadian agricultural diversification programs. Canada is now the world largest exporter of pea, lentil and chickpea and is fourth in dry bean. The demand for Canadian pulse products is steadily rising and the export market would continue to rise with the expected increased in production. Field pea exported to countries with tropical climates is at particular risk due to rapid loss of quality. It is therefore important to develop practical strategies for safe storage of feed pea. Knowledge on the moisture adsorption and spoilage characteristics of pea stored in adverse storage conditions is important in the transportation and storage of this export commodity.

This study was initiated to examine the conditions that lead to quality losses in storage and transport of pea. Tropical and subtropical conditions were simulated in airtight chambers. Relative humidities (RH) of 60, 70, 80 and 90% were created by saturated salt solutions in airtight chambers at temperatures of 10, 20 and 30°C, while the same range of humidity was provided by dilute sulphuric acid in airtight chambers at 40°C in environmental cabinets. The four RH levels at each temperature for both whole and feed-grade pea were tested in duplicate. The samples were observed for changes in moisture content (MC), mold appearance and RH in specific time intervals. The amount of produced carbon dioxide (CO_2) was measured in airtight chambers during storage to control the condition existing in sealed airtight chambers. Also, all components of feed-grade pea were exposed to RH of 90% and temperature of 40°C in separate airtight chambers to find the effect of each component on mold appearance. Molds were identified after appearance on the samples in order to pinpoint potential toxicity.

Both feed and whole sound peas became molded after a short time of storage at high temperatures and high RH, but those stored at 70% and below did not develop mold after 175 days at 30 and 40°C (experiment duration) and 216 days at 10 and 20°C (experiment duration). Molds were identified mostly as species of *Aspergillus* and *Penicillium*. The amount of CO_2 in the airtight chambers showed almost no difference from the ambient CO_2 except at high temperature and high RH when samples had gone molded.

Moisture adsorption equations were developed based on the moisture adsorption data in dynamic environment. Although the Page model showed to fit the data better, the exponential model was chosen to fit the data because its parameters can be better expressed as a function of temperature and RH of the storage environment.

The mold-free days for both feed pea and clean pea were modeled at temperatures of 10, 20, 30 and 40°C and RH of 80 and 90%.

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DEDICATION

Dedicated to my Mother, my father,

my husband and my son, Kaveh

TABLE OF CONTENTS

PERMISSION TO USE ii

ABSTRACT iii

ACKNOWLEDGEMENTS v

DEDICATION vii

TABLE OF CONTENTS viii

LIST OF TABLES xii

LIST OF FIGURES xvii

LIST OF ABREVIATIONS xxi

GLOSSARY OF TERMS xxii

1. INTRODUCTION 1

2. LITERATURE REVIEW 4

- 3.1 Effect of Moisture and Temperature on Fungal and Insect Growth 4
- 3.2 Respiration 8
- 3.3 Types of Grain Storage 9
  - 3.3.1 Controlled atmosphere storage 10
  - 3.3.2 Refrigerated storage 13
- 3.4 Storage of Pulses 14
  - 3.4.1 Storage of chickpea 15
  - 3.4.2 Storage of dry bean 16

3.4.3 Storage of field pea 19

3.5 Summary 28

3. OBJECTIVES 30

4. MATERIALS AND METHODS 32

4.1 Material 32

4.2 Experimental Equipment 35

4.2.1 Airtight chamber 35

4.2.2 Controlled environment cabinet 36

4.3 Protocols and Methods 38

4.3.1 Experimental plan for storage test in the static environment 40

4.3.2 Moisture adsorption of pea in dynamic environment 41

4.3.3 Relative humidity measurement in static environment 43

4.3.4 Maintenance of relative humidity inside the airtight chambers 44

4.3.5 Weighing of the samples in static environment 46

4.3.6 Measurement of CO_2 inside the chamber 49

4.3.7 Moisture content measurement 50

4.4 Data Analysis and Processing 53

4.4.1 Moisture ratio determination 53

4.4.2 Statistical analysis 54

4.4.3 Model development 55

5. RESULTS AND DISCUSSION 57

5.1 Moisture Adsorption of Pea in a Dynamic Environment 57

5.2 Moisture Adsorption of Pea and Components During Storage in Static Environment 63

5.3 Fungi Identification 73

5.4 Mold-free Days 79

6. CONCLUSIONS AND RECOMMENDATIONS 90

6.1 Conclusions 90

6.2 Suggestions for Future Research 92

6.3 Recommendations 93

LITERATURE CITED 94

APPENDIX A- MOISTURE ADSORPTION DATA 101

A.1 Moisture Adsorption in Dynamic Environment 101

A.2 Moisture Adsorption of Clean and Feed Peas during Storage in Static Environment 103

A.3 Moisture Adsorption Data of Feed Pea Components 118

A.3 Moisture Ratio Graphs 121

APPENDIX B – CARBON DIOXIDE MEASUREMENT 125

APPENDIX C- MICROBIAL TEST RESULT 129

APPENDIX D – STATISTICAL ANALYSIS 135

D.1 Sample SAS Input and Output 135

D.1.1 Sample SAS input 135

D.1.2 Sample SAS output 136

D.2 Sample ANOVA Tables and Residual Plots 148

D.2.1 ANOVA Table and Residual Plot in Dynamic Environment 148

D.2.1 Sample ANOVA Table and Residual Plots in Static Environment 151

APPENDIX E – APPEARANCE OF PEAS AT THE END OF STORAGE PERIOD. 154

LIST OF TABLES

Table 3.1 Minimum relative humidity for growth of common grain storage molds at 26-30˚C (Brooker et al., 1992). 6

Table 3.2 Equilibrium moisture contents (at 25°C) of common grains, seeds and feed ingredients at RH of 65-90% and fungi likely to grow (Sauer, 1992). 7

Table 3.3 Maximum temperature for chilled storage of grain (Bala, 1997). 13

Table 3.4 Suggested moisture content (%, w.b.) limits for good quality desi type chickpea and field pea seed stored at 20-30 °C for 3 and 9 months (Cassells and Caddick, 2001; Anonymous, 2003b). 15

Table 3.5 Effect of MC and temperature on storage life of chickpea (Anonymous, 2003b). 16

Table 3.6 Chemical compositions of feed pea (90% dry matter basis) and 100% whole or split green or yellow pea (Canada Feed Pea Growers Newsletter, 2000; USDA, 1998). 20

Table 3.7 Breakability and seed size of Dun-type field pea received at Wallaroo (NSW, Australia) grain terminal during the 1997/98 harvest (Cassells and Green, 1998). 21

Table 3.8 Number of weeks for safe storage of pea at specified grain MC and storage temperature (Sokhansanj and Patil, 1995) 26

Table 4.1 Typical compositions of pea samples by grade factors (Booth et al., 2001). 33

Table 4.2 Experimental plan for storage and moisture adsorption study in static and dynamic environment. 41

Table 4.3 Saturated salt and dilute sulfuric acid solutions used in the experiments (Bala, 1997; Rahman, 1995; Booth et al., 2001). 45

Table 5.1 Values of k and M_e obtained from non-linear regression analysis and from the experiment respectively for feed-grade pea. 60

Table 5.2 Values of k and M_e obtained from non-linear regression analysis and from the experiment respectively for clean pea. 61

Table 5.3 Initial moisture content of pea and components. 64

Table 5.4 Values of k and M_e in equation 4.2 obtained by NLIN regression analysis for feed pea. 71

Table 5.5 Values of k and M_e in equation 4.2 obtained by NLIN regression analysis for clean pea. 72

Table 5.6 Type of molds observed on both feed pea and clean pea after spoilage. 77

Table 5.7 Relative humidity and number of mold-free days for feed pea components. 80

Table 5.8 Relative humidity of storage chambers and number of mold-free days for whole sound pea. 81

Table 5.9 Relative humidity of storage chambers and number of mold-free days for feed-grade pea. 82

Table 5.10 Spoilage index values for clean pea. 87

Table 5.11 Spoilage index values for feed-grade pea. 88

Table A.1 Estimated parameters of moisture adsorption models for feed-grade pea. 101

Table A.2 Estimated parameters of moisture adsorption models for clean pea. 102

Table A.3 MC and RH of feed-grade and clean peas during storage at 10°C and 60% RH. 103

Table A.4 MC and RH of feed-grade and clean peas during storage at 10°C and 70% RH. 104

Table A.5 MC and RH of feed-grade and clean pea during storage at 10°C and 80% RH. 105

Table A.6 MC and RH of feed-grade and clean peas during storage at 10°C and 90% RH. 106

Table A.7 MC and RH of feed-grade and clean peas during storage at 20°C and 60% RH. 107

Table A.8 MC and RH of feed-grade and clean pea during storage at 20°C and 70% RH. 108

Table A.9 MC and RH of feed-grade and clean peas during storage at 20°C and 80% RH. 109

Table A.10 MC and RH of feed-grade and clean peas during storage at 20°C and 90% RH. 109

Table A.11 MC and RH of feed-grade and clean peas during storage at 30°C and 60% RH. 110

Table A.12 MC and RH of feed-grade and clean peas during storage at 30°C and 70% RH. 111

Table A.13 MC and RH of feed-grade and clean peas during storage at 30°C and 80% RH. 112

Table A.14 MC and RH of feed-grade and clean peas during storage at 30°C and 90% RH. 113

Table A.15 MC and RH of feed-grade and clean peas during storage at 40°C and 60% RH. 114

Table A.16 MC and RH of feed-grade and clean peas during storage at 40°C and 70% RH. 115

Table A.17 MC and RH of feed-grade and clean peas during storage at 40°C and 80% RH. 116

Table A.18 MC and RH of feed-grade and clean peas during storage at 40°C and 90% RH. 116

Table A.19 Mean RH and standard deviation for both feed-grade and clean peas during storage. 117

Table A.20 MC and RH data for whole green pea at 40°C and 90%RH. 118

Table A.21 MC and RH data for Shrivelled yellow and green peas at 40°C and 90%RH. 118

Table A.22 MC and RH data for cracked seed coat yellow and green peas at 40°C and 90%RH. 119

Table A.23 MC and RH data for split yellow and green peas at 40°C and 90%RH. 119

Table A.24 MC and RH data for small yellow and green peas at 40°C and 90%RH. 119

Table A.25 MC and RH data for other damaged yellow and green peas at 40°C and 90%RH. 120

Table A.26 MC and RH data for foreign materials at 40°C and 90%RH. 120

Table B.1 Concentration of CO_2 during storage at 10°C and RH of 60 to 90%. 125

Table B.2 Concentration of CO_2 during the storage at 20°C and RH of 60 to 90%. 126

Table B.3 Concentration of CO_2 during the storage at 30°C and RH of 60 to 90%. 127

Table B.4 Concentration of CO_2 during the storage at 40°C and RH of 60 to 90%. 128

Table C.1 Fungi isolated from spoiled pea samples. 129

Table D.1 Summary output for clean pea for k as a function of temperature and relative humidity 148

Table D.2 Summary output for feed pea for k as a function of temperature and relative humidity 149

Table D.3 Summary output for clean pea for k as a function of temperature and relative humidity 151

Table D.4 Summary output for feed pea for k as a function of temperature and relative humidity 152

LIST OF FIGURES

Figure 4.1 Petri dishes arrangement on the shelves. 33

Figure 4.2 Sample of whole yellow pea 34

Figure 4.3 Sample of feed-grade pea. 34

Figure 4.4 Different components of airtight chambers. 36

Figure 4.5 Controlled environment chamber. 37

Figure 4.6 Angelantoni environmental chamber. 38

Figure 4.7 The environmental chamber of the thin layer dryer. 39

Figure 4.8 Measuring of the RH within the airtight chamber. 44

Figure 4.9 Weighing the samples inside the airtight chamber. 47

Figure 4.10 Taking CO_2 sample by inserting a 20 mm syringe beside the rubber stopper. 49

Figure 4.11 Feed-grade pea molded at 40°C and 90% RH. 52

Figure 4.12 Whole sound pea molded at 40°C and 90%RH 52

Figure 5.1 Fit of four moisture adsorption models to the experimental data for clean and feed peas at T=40°C, RH= 90%. 59

Figure 5.2 Moisture content of clean and feed-grade peas during storage at 40°C and RH of 60, 70, 80 and 90%. 62

Figure 5.3 Moisture content of feed-grade and clean peas during storage at 10°C and RH of 60, 70, 80 and 90%. 65

Figure 5.4 Moisture content of feed-grade and clean peas during storage at 20°C and RH of 60, 70, 80 and 90%. 66

Figure 5.5 Moisture content of feed-grade and clean peas during storage at 30°C and RH of 60, 70, 80 and 90%. 67

Figure 5.6 Moisture content of feed-grade and clean peas during storage at 40°C and RH of 60, 70, 80 and 90%. 68

Figure 5.7 Moisture content of feed pea components during storage at 40°C and 90% RH. 69

Figure 5.8 Moisture content of feed-grade pea during storage at temperatures of 10, 20, 30 and 40°C and RH of 90%. 70

Figure 5.9 Final moisture content of feed-grade pea for given storage temperature and relative humidity. 73

Figure 5.10 Photograph of the *Aspergillus* appeared on clean pea at 40°C and 90% RH. 75

Figure 5.11 Photograph of the fungi appeared on feed pea at 40°C and 90% RH. 76

Figure 5.12 Photograph of the fungi that appeared on feed pea at 10°C and 90% RH. ... 76

Figure 5.13 Feed pea surface condition after 64 days of storage at 10°C and 78.2% RH (a); and after 105 days at 10°C and 80.5% RH (b). 83

Figure 5.14 Clean pea and feed pea surface condition at 20°C and 80% RH after 76 (a) and 56 (b) days of storage, respectively. 84

Figure 5.15 Clean pea and feed pea appearance at termination of storage at 30°C and 90 and 80% RH for 31(a) and 34 (b) days respectively. 85

Figure A.1 Moisture ratio vs. storage duration for feed pea and clean pea at 10°C. 121

Figure A.2 Moisture ratio vs. storage duration for feed pea and clean pea at 20°C. 122

Figure A.3 Moisture ratio vs. storage duration for feed pea and clean pea at 30°C. 123

Figure A.4 Moisture ratio vs. storage duration for feed pea and clean pea at 40°C. 124

Figure D.1 Plot of residual vs. relative humidity and temperature for feed pea............ 150

Figure D.2 Plot of residual vs. relative humidity and temperature for clean pea. 150

Figure D.3 Plot of residual vs. temperature and relative humidity for feed pea............ 153

Figure D.4 Plot of residual vs. temperature and relative humidity for clean pea. 153

Figure E.1 Clean and feed pea appearance after 163 days of storage at 10°C and 60%RH. 154

Figure E.2 Feed and Clean pea appearance after 212 days of storage at 10°C and 70%RH. 155

Figure E.3 Appearance of clean pea after 104 and 119 days of storage at 10°C and 90 and 80% RH respectively. 156

Figure E.4 Appearance of clean and feed peas after 216 days of storage at 20°C and 60% RH. 157

Figure E.5 Appearance of clean and feed peas after 216 days of storage at 20°C and 70% RH. 158

Figure E.6 Appearance of clean and feed peas after 42 and 35 days of storage at 20°C and 90% RH respectively. 159

Figure E.7 Appearance of clean and feed peas after 162 days of storage at 30°C and 60% RH. 160

Figure E.8 Appearance of feed and clean peas after 156 days of storage at 30°C and 70% RH. 161

Figure E.9 Appearance of feed and clean peas after 174 days of storage at 40°C and 60% RH. 162

Figure E.10 Appearance of feed and clean peas after 174 days of storage at 40°C and 70% RH.. 163

Figure E.11 Appearance of feed and clean peas after 34 days of storage at 40°C and RH of 80% and 90% respectively. 164

Figure E.12 Appearance of whole green and split yellow and green peas after 15 and 9 days of storage at 40°C and 90%RH respectively. 165

Figure E.13 Photographs of cracked seed coat and shriveled peas after 15 days of storage at 40°C and 90%RH... 166

Figure E.14 Photographs of other damaged pea and small pea after 6 and 15 days of storage at 40°C and 90% RH respectively... 167

Figure E.15 Photographs of foreign materials after 9 days of storage at 40°C and 90%. 168

LIST OF ABREVIATIONS

CO_2	Carbon Dioxide
CA	Controlled Atmosphere, a type of storage
d.b.	Dry basis, moisture content is expressed with respect to the dry-mass of the pea.
EMC	Equilibrium moisture content
ERH	Equilibrium relative humidity
FAV	Fat acidity value
FM	Foreign material, a component of feed grade pea.
MC	Moisture content
O_2	Oxygen
RH	Relative humidity
w.b.	Wet basis, moisture content is expressed with respect to the initial mass of the pea.

GLOSSARY OF TERMS

Clean pea	Referred to whole sound pea, which are hand sorted for qualities such as smoothness and roundness.
Feed pea	Referred to pea components plus foreign material, hand mixed to reflect typical composition of feed-grade pea.
Foreign material	Foreign material in feed pea is defined as any material other than whole pea, broken pea and pea seed coats.
Air tight chamber	Referred to chambers which are sealed from outside in order to produce desirable condition for the sample
Relative humidity	Defined as ratio of vapor pressure of water in the air to the vapor pressure of the water in saturated air at the same temperature and atmospheric pressure.
Equilibrium moisture content	Moisture content of the material after it has been exposed to a particular environment for an infinitely long period of time.
Moisture Adsorption	The process by which a relatively dry product attain its equilibrium moisture content by gaining moisture.
Putative species	Categorization of fungi species in a formal manner that could be recognized by everyone.

1. INTRODUCTION

Field pea (*Pisum sativum* L.) is an annual cool-season legume crop that is grown on over 25 million acres worldwide. Field pea or "dry pea" is marketed as a dry, shelled product for either human food or livestock feed. The major producing countries of field pea are Russia and China, followed by Canada, Europe, Australia and the United States. Europe, Australia, Canada and the United States raise over 4.5 million acres and are major exporters of pea (Anonymous, 2003a).

Pea is among the world's oldest crop as it was first cultivated 9000 years ago. Early in the 20th century, Ontario and then Manitoba led in the Canadian pea production. Since the mid 1980's, Saskatchewan has produced the majority of Canadian field pea (70%) with significant acreage in Alberta (25%) and Manitoba. Ontario is no longer a large-scale producer. About 35% of the dry pea produced in Canada is consumed domestically, with the largest use being livestock feed, followed by seed and food. Most of the increase in domestic use is due to greater use for livestock feed in the Prairie Provinces, especially for feeding hogs (Anonymous, 2003a; Agriculture and Agri-Food Canada, 2004).

As Canada's pulse industry has grown dramatically over the past 15 years, Canada is now the world largest exporter of pea, lentil and chickpea. Future world markets for pulse crops will likely continue to grow because the importing countries have increasing populations and the major feed pea importers are turning to vegetative protein sources for animal feed. Pea is the only pulse crop used as feed because other major pulse crops are only used for feed when their quality do not meet the food market. Work needs to be done on feed pea, such as reducing the amount of foreign material (FM) from 8% to 1%, as high percentage of FM could not be tolerated by Europe, Canada's major pea export customer (Saskatchewan Pulse Growers, 2002).

Pea and other pulse grains are graded according to the following factors: a) moisture content (MC); b) size; c) damage (split or broken materials); d) odor; e) color; and, f) foreign materials (FM) (including non-pulse grains, chaff, stones, and microbial count for mold and fungus growth). Like other grains, pulse grain quality deteriorates with storage time (Pulse Canada, 1997). The most rapid deterioration occurs under conditions of high temperature and moisture. Pulses harvested at or above 15% (wet basis) moisture must be aerated and dried to 8-11% for safe storage. (Unless otherwise indicated, moisture content in this document is expressed in % wet basis (w.b.)). Reducing storage moisture and temperature generally increases the storability of pulse grains (Whitcombe and Erskine, 1984; Cassells, 1996).

Three major grades are generally used for field pea other than green pea in descending order of quality: a) No. 1 Canada; b) No. 2 Canada; and c) No. 3 Canada. The maximum limits of yellow field pea used for human consumption are less than 0.05% FM (ergot) for all grades: 3, 5 and 10% total damage (splits or broken, shriveled, heated, insect damage or other damage), and 1, 2 and 3% content of pea of other colors, for No. 1 Canada, No. 2 Canada and No. 3 Canada, respectively (Canadian Grain Commission, 2003).

In the export market, feed pea is classified as mixture of green and yellow peas with various specifications on moisture, FM and percentage of pulses other than green and yellow peas. Mixtures of pea falling below No. 3 Canada are graded as feed pea. The maximum allowable level of FM is 6% for feed pea. However, it is not uncommon for

Canadian marketing companies to ship feed pea with 8% or more FM. The quality of feed pea is affected significantly by FM level and composition. At a given storage temperature and RH, FM may adsorb moisture differently from the pea. Generally, the FM adsorb more moisture; thereby increasing the susceptibility of feed pea to microbial development and quality deterioration. Apart from accumulating adsorbed moisture, FM may also block natural or forced airflow in storage, thus creating an environment conductive to localized mold development (Booth et al., 2001).

Feed pea is generally shipped bulk by rail, from the elevators to ports and other markets. Food pea is also generally shipped by rail, either bulk, in bags or in containers (Agriculture and Agri-Food Canada, 2004). Canada is a temperate country, so there is usually no concern for feed pea storage, but as this commodity is exported to tropical countries the potential for product spoilage in transit or at shipment destinations is relatively high, due to exposure to high RH and variable temperature conditions. Moisture condensation is also likely to occur due to the contact of cold material (pea) with warm air. These adverse conditions influence the water uptake of pea. Biochemical reactions and the activity of microorganisms are also influenced by the RH and temperature of the surrounding air. These environmental conditions affect mold growth and the stability of pea during storage and transport. Thus, it is important to gain knowledge on water adsorption of feed pea and what happens to feed pea in adverse conditions of temperature and humidity. Molding of this commodity may render it toxic even to animals.

2. LITERATURE REVIEW

Canadian pea exports to tropical and subtropical countries account for about 60% of the total exported pea. It is important to know what happens to feed-grade pea when it reach the export destination with humid and warm conditions. The following review examines the effect of temperature and moisture on quality changes and mold contamination of legume seeds and the effect of storage on the quality factors of chickpea, dry bean and pea.

3.1 Effect of Moisture and Temperature on Fungal and Insect Growth

Temperature control is a major management tool to regulate insects and molds in stored grains. Grain moisture is the other critical grain management factor that regulates storability**.** Thus, moisture and temperature are the most important factors in storage of grains and grain products that influence the rate of deterioration during storage. Moisture migration in storage results from temperature gradients within the grain bulk. The higher the moisture content (MC) of the grain and the greater the temperature difference within the grains, the more rapid the moisture transfer will be (Bala, 1997; Anderson and Alcock, 1954; Christensen, 1982). Safe storage of a commodity depends largely on its MC (more strictly, the RH of the intercellular atmosphere), temperature, storage duration and grain conditions (Mills and Woods, 1994; Sauer, 1992).

Most rapid deterioration occurs under conditions of high temperature and moisture. Seeds that have been stored under these conditions may have poor germination and mergence. Pulses harvested at MC at or above 15% require careful management during storage. In general, drier seed can be more safely stored. At moisture levels of 8-11% in the seed, there is no risk of damage if the seeds are placed in cold storage. Damage from being too dry occurs below 2% moisture content. Reducing MC and temperature increases the longevity of the seed (Kosolofski et al., 1998).

Fungi are the major cause of deterioration and decay in stored grains. Invasion by storage fungi may increase the equilibrium moisture content (EMC) at the RH that permits their growth, for this reason RH rather than the MC is suggested to be used as the measure of the grain's liability to attack by storage fungi. RH decreases with increasing temperature at constant MC. The major storage fungi comprise only of a few species of *Aspergillus* that grow in nearly dry condition and several species of *Penicillium* that grow mainly in grains of high moisture content stored at low temperatures. A variety of other fungi may grow in high moisture grain before drying or in grains that become wet during storage. *Rhizopus, Mucor*, and *Nigrospora* are among the most common of these (Christensen, 1982; Bala, 1997; Justice and Bass, 1978; Brooker et al., 1992; Sauer, 1992).

Table 3.1 shows the minimum RH for growth of common grain storage molds at 26-30˚C. The physical condition, viability and MC of the seed and the ambient temperature and RH of the storage area largely determine fungal activity. Consequently, the fungal population reflects the kind and efficiency of the postharvest handling, conditioning and storage environment of the seed lot (Justice and Bass, 1978).

Table 3.1 Minimum relative humidity for growth of common grain storage molds at 26-30˚C (Brooker et al., 1992).

Mold species	Minimum relative humidity (%)
Aspergillus halophilicus	68
A .restrictus, Sporedonema	70
A. glaucus	73
A. candidus, A. ochraceus	80
A. flavus	85
Penicillium, depending on species	80-90

An important and often overlooked consideration in seed storage is the quality of seed placed in the storage. Seed germination provides a good indication of seed condition. Good quality seed stores well even under relatively adverse conditions, while poor quality seed deteriorates rapidly even under favorable conditions (Cassells and Caddick, 2001; Anonymous, 2003b).

Table 3.2 shows the EMC and fungi likely to grow during storage. EMC is closely related to the RH of the storage atmosphere as shown in this table. Sauer (1992) reported some of the major storage fungi in soybeans, such as, *Aspergillus restrictus* that grows at 12-12.5% MC, *A. glaucus* that grows at 12.5-13% MC, *A. candidus* begins growing at 14-15% MC, *A. ochraceus* starts growing at 14.5-15% MC, and *A. flavus* that grows at 17-17.5% MC or higher.

Christensen (1982) stated that pests have optimal zones of moisture and temperature in which they grow well. Grain-eating insects have a thick cuticle, largely impermeable to moisture, and a physiology that enables them to conserve moisture and resist death by

Table 3.2 Equilibrium moisture contents (at 25°C) of common grains, seeds and feed ingredients at RH of 65-90% and fungi likely to grow (Sauer, 1992).

	Equilibrium moisture content (% w.b.)			
Relative humidity (%)	Starchy cereal seeds, defatted oilseed meals, alfalfa pellets	Soybeans	Peanuts, sunflower, rapeseed	Fungi
65-70	12-14	11-12	6-8	*Aspergillus halophilicus*
70-75	13-15	12-14	7-10	*A. restrictus, A. glaucus* *Wallemia sebi*
75-80	14-16	14-16	8-11	*A. candidus, A. ochraceus,* plus the above
80-85	15-18	16-19	9-13	*A. flavus, Penicillium spp.* plus the above
85-90	17-20	19-23	10-16	Any of the above

desiccation even in very dry grain. The temperatures required for their activity are relatively high, usually above 15°C, with an optimum in the range of 28-38°C for different species. For mites, which have a thin covering and can be killed by exposure to humidities below 60%, the optimum temperature for rapid breeding is lower than for insects; mites remain active at temperatures as low as 4 to 10°C, depending on the species. By contrast, fungi can grow or survive at a wide range of temperatures from below freezing to near 50°C but with few exceptions require a RH above 70% for significant growth. The hazards from pest attack are therefore determined by the temperature and MC combinations achieved during storage. The ideal situation is to maintain a low temperature which will inhibit insects, and low moisture to limit fungi, mites, and metabolic activity in the seed. Storage time is also important because in a short storage period, pests may not have time to cause measurable damage (Christensen, 1982).

3.2 Respiration

Respiration is an oxidative-reduction process that occurs in all living cells. Since stored grains are living materials, respiration is primarily responsible for heating. Molds also play an important role in primary heating of grains. Many investigators believe that the heat produced in stored damp grain is both due to the respiration of the grain itself and to the growth of fungi. Insects also contribute to the total respiration and heat production in infested grain (Anderson and Alcock, 1954; Bala, 1997).

Various factors influence the respiration of grain such as MC, temperature and aeration. Bala (1997) reported that heat generated during respiration in most grains is mainly from the respiration of fungi and not from the grain. However, insects respire and produce heat as well. Milner and Geddes (as cited by Anderson and Alcock, 1954) also showed that mold growth is mainly responsible for the high rate of respiration. They pointed out that the MC of any particular grain is the main factor, along with temperature, that determines the intensity of respiration. A marked increase in respiration for different grains occurs at a rather constant RH of 75% in the intergranular atmosphere, at which the EMC of different grains may vary markedly. This fact clearly indicates that the total MC of the grains is not the controlling factor. On the other hand, only that part of the total water which is free to exert vapor pressure is significant and the water activity must be approximately 0.75. The MC at which mold growth begins is also the one at which a marked increase in CO_2 production was observed.

Under favorable storage conditions, the heat of respiration is of little concern for practical seed storage; however, at higher moisture level, the heat of respiration can produce much damage to stored seed as high temperature does (Justice and Bass, 1978). Respiration of microflora plays a major role in grain deterioration. The direct effects of respiration are weight loss due to moisture loss of the grain, accompanied by a rise in carbon dioxide level in the intergranular air, and a rise in grain temperature. The degree or intensity of grain respiration and fungi respiration determines the rate and extent of deterioration of the grain bulk (Salunkhe et al., 1985).

Respiration can be controlled by lowering the temperature and MC of the grain, limiting the O_2 content and increasing the CO_2 content of the atmosphere and treating the grain with chemicals. Time is an important factor because the control becomes more complicated as the length of storage period increases (Bala, 1997). The most effective method of keeping respiration of stored seed at a minimum is to keep the seed dry. The seed should be dried to a MC safe for storage and should be held at a RH that will maintain a safe MC throughout storage (Justice and Bass, 1978).

3.3 Types of Grain Storage

In many parts of the world, the MC of grain at harvest is too high for subsequent safe storage. Such damp grain is readily attacked by molds and mites unless it is protected in some way. The most widely used method of preventing mold growth and infestation by mites is to dry the grain to a safe level of MC, but protection by airtight storage, preservative chemicals, or by forced cooling using fresh or refrigerated air are also used under some circumstances. Drying alone is not enough against all organisms, because it may still be damaged by insects or may require cooling to protect it from insect attack. For most spoilage organisms and biological materials, the rate of spoilage is related to MC and temperature; therefore reduced temperature enable grain to be stored safely at higher MC (Christensen, 1982). The following two types of storage are discussed as they are related to this research.

3.3.1 Controlled atmosphere storage

The benefits of airtight storage in preserving grain quality have long been recognized, but raising CO_2 concentration has recently been considered. Increase in CO_2 level is effective in limiting the growth of many molds, yeasts, and bacteria (Sauer, 1992).

The term airtight storage is used to describe the process whereby the grain is held in airtight silo in which depletion of oxygen (O_2) from its normal level of approximately 21% results in suppression of organisms, which would otherwise cause grain deterioration. Living organisms respire during storage. For respiration, they need O_2 that is obtained from air. Most fungi need O_2 for respiration, and would die or at least cease to develop in conditions of low O_2, although some fungi need only minute quantities of O_2 for their growth. Other organisms including certain yeasts and bacteria can respire in the complete absence of O_2 (anaerobic respiration). Anaerobic respiration, which is the characteristic of certain microorganisms, occurs in airtight containers only at high humidity level, i.e., the grain is damp (Bala, 1997).

Controlled atmospheres (CA) are used as periodic treatments to control pest in stored grain or, less frequently, as long-term storage environments to prevent pest occurrence (insects, mites and molds). The CA contains either high levels of CO_2 or high levels of nitrogen (N_2), with virtual elimination of O_2. CO_2 is generally favored because moderate levels of CO_2 will kill insects even at relatively high O_2 levels. The use of CA storage in relatively airtight structures is economically competitive with fumigation using phosphine gas, where insect resistance to it is becoming more widespread. Besides, CA is safe to apply. Although CO_2 is a greenhouse gas, the gas used in CA is a by-product of industrial or natural processes (White and Jayas, 2003).

Whether the grain is dry or damp, successful airtight storage depends on the depletion of oxygen in sealed containers to a level lethal to the organisms (insects or molds) produced by their own activity before they multiply enough to damage the grain. Scientific investigations on airtight storage of dry grain in series of tests have shown that in sealed containers, the insects are killed when most of the oxygen has been used by the respiration of insects themselves. Since then, many researchers have shown that it is the removal of oxygen rather than the accumulation of carbon dioxide that kills the insects. Research has shown that in completely sealed containers, oxygen was reduced to a lethal level in about 21 days. In practice, most of the commercial airtight containers have a slight leak that allows entry of oxygen and escape of CO_2. Investigations showed that in laboratory test of containers with a slight leak (0.5% re-entry of oxygen per day), heavy infestation was eliminated. After insects are killed, the oxygen can rise again at a rate equal to the leakiness of the container, this O_2 falls again as it is used by the remaining insects and the cycle is repeated (Bala, 1997). In warm climate, even if an infestation is not completely eliminated, partial control is a valuable achievement, as it delays or even prevents the development of a heavy infestation, greatly reduce the amount of damage to the grain.

In damp grain, microorganisms are mostly fungi that create oxygen-free conditions. Most molds need oxygen for their growth, and die or at least become inactive in its absence. In oxygen-free conditions, certain microorganisms such as yeasts and bacteria can grow, and their respiration results in production of alcohol and volatile substances. At MC above 16% after O_2 is eliminated, anaerobic build up of CO_2 may occur to as much as 95% of the air depending on the MC in completely sealed airtight chambers. But in commercial silos, there is usually some escape of CO_2, therefore, the concentration falls between 15 and 25%. Damp grains stored in sealed containers are normally unacceptable for human consumption, although suitable for animal feed. The gluten in the grain is affected; germination capacity is also reduced making the grain unsuitable for seeding. Because of other factors including hazards arising from toxins produced by molds, airtight storage of high moisture grain (more than 13%) cannot be recommended for widespread use under tropical conditions (Bala, 1997).

Increase in CO_2 concentration at a constant RH and temperature produces increased insect mortality with decreased exposure time. The effectiveness of CO_2 is reduced with decreasing temperature and increasing RH. Grains adsorb CO_2 at varying rates. This adsorption can cause partial vacuums in sealed bins and affect the levels of intergranular CO_2 available to kill insects. Fumigation of grain with CO_2 requires the maintenance of high CO_2 concentration (20-60%) for extended periods (>4 days). Grain storage structures currently used on Canadian farms are not airtight and should be sealed if they are to be used for fumigation with CO_2. Currently, bins with CA capacity are being installed in a newly constructed grain terminal elevator in Canada. The use of CA in grain storage can be practical and cost effective if supplies of CO_2 and airtight structures are available (White and Jayas, 2003).

3.3.2 Refrigerated storage

Cooling grain with refrigerated air in an aeration system is another method of preserving high moisture grain without using chemicals or holding ahead for the dryer. The relationship of grain storage temperature and MC to grain deterioration is such that the lower the temperature of the grain, the higher the MC at which it can be successfully stored. This characteristic is illustrated in Table 3.3.

Table 3.3 Maximum temperature for chilled storage of grain (Bala, 1997).

	Temperature	
Grain moisture content (%)	Freedom from all deterioration after 8 weeks storage	Freedom from mold but 5% loss of germination
16	13°C	15°C
18	7°C	10°C
20	4°C	7°C
22	2°C	4°C

Chilled aeration allows for conditioning of large masses of grain to a desired temperature and moisture level at any time during the storage season. As a result, grain chilling provides a non-chemical conditioning and preservation technology for good quality grains. This low temperature preservation method is an alternative to treating food grains with pesticides for product quality control (Maier et al., 1996). Refrigeration does not eliminate all risks of spoilage. However, some fungi will grow when sufficient moisture is present at temperature below freezing. Therefore, the MC of the grain being refrigerated is also very important (Christensen and Kaufmann, 1969)

The refrigeration or chilling of grain is usually achieved by passing fresh or recirculated air through a refrigerated coil that cools the air below ambient temperature before blowing it into the grain bulk. Air temperatures between 5 and 10°C are usually selected, but it may be higher or lower depending on the MC of the grain. The RH chosen for the conditioned air is usually between 60 and 70% of saturation, but may be controlled to a higher or lower level depending on the MC of the stored grain. Cooled storage reduces the risk of damage by insects, and maintenance of temperatures between 5 and 10°C prevents insects from proliferating. Cooling also reduces fungal and mite activity and intermittent cooling can prevent the formation of hot spots by removing the metabolic heat produced by grain organisms. Cooling eliminates temperature gradients in a bulk, thus, inhibiting moisture migration that would otherwise cause mold growth and grain sprouting, and maintaining the chemical and biological properties of the stored material for longer periods (Christensen, 1982).

3.4 Storage of Pulses

Grain handling and storage conditions for pulses are important for insect control and grain quality. High temperature, high RH, high seed MC and an extended storage period have all been found to adversely affect their quality during storage.

3.4.1 Storage of chickpea

Chickpea has been shown to have different storage characteristics from field pea and is likely to spoil more rapidly under similar conditions. The MC limits suggested for the safe storage of desi-type chickpea and field pea are shown in Table 3.4. Storage at lower moisture contents is suggested to minimize darkening and color loss from the seed coat. Lower seed MC influences the susceptibility of chickpea seed to break during handling, also delay in harvest to obtain low moisture levels can result in substantial weather damage. Suitable moisture level and temperature for seed storage is very important (Cassells and Caddick, 2001).

Table 3.4 Suggested moisture content (%, w.b.) limits for good quality desi type chickpea and field pea seed stored at 20-30 °C for 3 and 9 months (Cassells and Caddick, 2001; Anonymous, 2003b).

Pulse type	20°C		30°C	
	3 months	9 months	3 months	9 months
Chickpea-desi type (var. Amethyst)	14.0	13.0	13.0	12.0
Field pea (var. Dun type)	14.5	13.5	13.5	12.5

Desi chickpea will darken considerably and seed germination will decline in storage, with rate being accelerated by high seed MC, high temperatures, high RH and condition of the seed at harvest. Table 3.5 shows the effect of MC and temperature on the storage life of chickpea (Anonymous, 2003b; Cassells and Caddick, 2001).

Table 3.5 Effect of MC and temperature on storage life of chickpea (Anonymous, 2003b).

Storage moisture (%)	Storage temperature (°C)	Longevity of seed (days)
12	20	More than 2000
12	30	500-650
12	40	110-130
15	20	700-850
15	30	180-210
15	40	30-50

Attention to storage conditions is particularly important when the seed is being stored for more than one season. Research has shown that dry seed (10% or lower MC) stores well at storage temperatures of up to 30°C. Pulses harvested at MC of 15% or above require careful management during storage; aeration may be used to reduce and provide a uniform storage temperature (Cassells, 1996).

According to Whitcombe and Erskine (1984) longevity of chickpea grains stored at 15% MC and 30°C was 110 to 115 days while at 15% MC and 40°C, the longevity reduced to between 20 and 30 days and 100 to 105 days at 40°C and 12% MC. At 20°C storage temperature and 12 to 15% MC, the longevity increased to about 1000 days. Microbial activity increased with higher MC and temperature, and microbial count above certain limits led to undesirable odor and color changes in pea.

3.4.2 Storage of dry bean

Common food legumes, in particular common dry beans, are harvested in periods of the year when there is rainfall, thus, they must be dried for storage. The removal of excess moisture by sun drying, if not controlled, may initiate a condition known as hardening. This is more noticeable during storage at high temperature and high RH. Therefore, the nutritional value of beans is affected by a variety of factors during storage and processing. Poor storage of common beans will increase the hard-to-cook problem. Bressani (1982) stored beans for 0, 3 and 6 months at 35°C and 85% RH. At the end of each experiment, samples were cooked under standard procedure at atmospheric pressure and their hardness was measured by the Instron texturometer. It took 150 min at atmospheric pressure to soften the samples stored for 0 month. However the samples stored for 3 months required 170 min, while those stored for 6 months were still uncooked even after 210 min. This experiment investigated three factors, namely, storage temperature and time, RH, and the MC of the seed. High moisture in the grain favors hardening as storage time increases. The hard-to-cook phenomenon that develops in food legumes under improper storage condition is not fully understood. Available evidence suggests that an increase in the bound protein takes place in the seed coat and aleurone layer, although the cotyledons also lose their capacity to absorb water because of changes in pectin and calcium ions. The grey color that very often develops is suggestive of carbohydrates-protein reactions (Bressani, 1982).

In beans, storage problems result in the loss of grade, including crusting and discoloration of the top layer caused by molds. Molds cause spoilage, discoloration and heating. Safe storage of a commodity depends largely on its MC (more strictly, the RH of the intergranular atmosphere), its temperature, the period of storage, and other factors (Mills and Woods, 1994).

A study on extractable protein from defatted soy meal and whole beans during six months of storage was conducted at four storage temperatures and four RH conditions

(25°C, 50% RH; 25°C, 85% RH; 35°C, 50% RH; and 35°C, 85% RH). It was reported that the amount of extractable protein decreased with time in both defatted meal and whole beans in all combinations of temperature and RH. The rate depends on storage conditions, the higher the temperature and humidity, the lower is the protein extractability. The MC (or RH) appeared to have a stronger effect than the storage temperature. Also with the same storage condition, defatted soy meal showed a more rapid decrease in protein extractability with time than whole bean (Anonymous, 2003c).

El-Tabey Shehata et al. (1984) reported that the physical properties of faba beans were affected by the type of container; airtight containers were better than others for maintaining cooking quality and for controlling infestation. Infestation was also controlled by admixture treatments (admixture with sand or wood ash and lining the container with fenugreek straw) in ceramic containers. Roasting was the best experimental treatment for maintaining cooking quality, but supplementary comparisons suggested that underground storage gave the best results overall.

Storage fungi were studied by Hellevang et al. (2001). It was noted that storage fungi could cause germ damage, heating, caking, bin burning and mustiness if left unchecked. Increase in temperature and storage time at 79% to 100% RH range caused an increase in mold growth. Mold growth was reported to occur at 75% RH at temperatures above 12°C in a static system. Often, early stages of fungal growth are undetectable by visual inspection but can be detected by culture techniques. The use of a Hunter colorimeter has proven that beans should be cooled as rapidly as possible and stored at 4°C or lower to maintain color and cooking quality. If the beans cannot be cooled, then MC should be less than 13% for storage.

3.4.3 Storage of field pea

Water is an important component affecting physical properties of food materials. Water exists in the form of free and bound water. Water is adsorbed or desorbed depending on molecular structure of material (Mohsenin, 1986).

Equilibrium moisture, defined as the final moisture that will be reached at a specific temperature and RH, affects the rate of water adsorption or desorption. The corresponding air RH is called equilibrium relative humidity. EMC at a given RH decreases with increase in temperature. EMC depends on grain composition. The structure of the grain is responsible for water adsorption rate. For example, the lesser is the amount of fat, the higher will be the EMC at the same condition of temperature and RH because increase in oil content decrease water adsorption of the material. High amount of starch, which is a hygroscopic component, increases water attraction. It takes longer for water to penetrate inside wheat kernel with higher amount of protein in comparison to kernel with lower amount of protein. As a result the lesser the amount of protein the higher is the water adsorption of the material (Stroshine, 1998).

The compositions of feed pea and whole or split yellow or green pea are listed in Table 3.6. The highest chemical component in pea as in other legumes is carbohydrate, which constitutes about 56.6% of seed weight. Starch constitutes a larger part of the carbohydrate (36.9-48.6%), while amylose is about 34% of seed weight in pea (Muehlbauer and Tullu, 1997). A high moisture adsorption in pea is expected because of the high amount of carbohydrate and low amount of lipid.

Table 3.6 Chemical compositions of feed pea (90% dry matter basis) and 100% whole or split green or yellow pea (Canada Feed Pea Growers Newsletter, 2000; USDA, 1998).

Nutrient	Amount		Unit
	Feed pea	Whole green and yellow pea	
Water	NA	11.3	g
Energy	NA	341.0	Kcal
Protein	22.6	24.6	g
Total Lipid	1.1	1.2	g
Carbohydrate	46.8	60.4	g
Fiber	30.34*	25.5	g
Ash	NA	2.7	g

* Consists of 5.5% crude fiber, 8.19% acid detergent fiber and 16.65% neutral fiber.

Existing data on safe storage of pea are primarily those reported by Kreyger (1972) for temperate climates. Kreyger's safe storage criteria were based on germination loss, which is not applicable to feed pea. The data assumed clean grain and covered a temperature range of 5 to 25°C, and the data has never been challenged with modern experimental techniques. Several studies have been conducted on pea by other researchers since then, which are briefly reviewed as follows.

Powell and Matthews (1978) studied samples of 13 seed lots from six cultivars of pea drawn from commercial warehouses followed by storage of up to two years. With increased time in storage, a decline in seed vigor was indicated by an increase in the leaching of electrolytes from the seeds and reduced vital staining, although the viability was still maintained at a level above the minimum standard (80%). They proved that the response of seed lots to storage in laboratory conditions was indicative of the prolonged storage. The conductivity of 7 seed lots measured after 1 day in 94% RH and 45°C temperature was also positively correlated with conductivity readings obtained after one year of commercial storage. The decline in vigor during warehouse storage is indicative of low vigor seed lots in pea. Therefore, the evaluation of the storage potential of seed lots would be appropriate by using a laboratory storage test such as conductivity measurements.

Study on breakability and size of field pea by Cassells and Green (1982) showed that delay in harvest affects postharvest breakage to a greater degree than seed MC. As reported in their study, field pea received and stored at the higher moisture level showed improved handling characteristics. The result of this study is shown in Table 3.7.

Table 3.7 Breakability and seed size of Dun-type field pea received at Wallaroo (NSW, Australia) grain terminal during the 1997/98 harvest (Cassells and Green, 1998).

Date of receipt	Average moisture (% w.b.)	Breakability (%)	Seed size (%) Screen aperture (mm)		
			7	6	<6
High moisture					
(12-13.5)(10-20/11/97)	12.4	0.9	45.6	44.0	10.4
Low moisture					
(<12%) (12-20/11/97)	10.9	1.1	32.8	47.8	19.5
(11-19/12/97)	8.6	3.1	12.9	50.8	36.3

Gorecki et al. (1985) investigated the proteins of pea seeds stored at 50 and 90% RH after 7 months. After 7 months at 90% RH, there was marked deterioration of seeds and germination was below 20%; germinating seeds produced smaller seedlings. Seeds stored at 50% RH were not affected. Deterioration of seeds caused a change in proteins of seeds with decreased vigor and viability. The albumin fraction decreased by roughly 40% and the vicilin content was twice as high in the deteriorated seeds compared to the ones that did not deteriorate. However, ligumin levels were unchanged.

Ehiwe et al. (1987) studied seed coat durability of field pea as affected by seed MC and temperature. The temperatures used were -40, -25, -10, 6, 24 and 40°C. MCs used were 6.3, 9.1, 11.3, 14.8 and 18.3%, which were obtained by letting the seed equilibrate in RH of 11, 33, 52, 75 and 90%, respectively. Results showed that at all temperature levels, seed coat breakage increased linearly with decreasing MC. In most cases, the breakage increased with a decrease in temperature. It was recommended that pea should not be handled at MCs below 14% or temperatures below -25°C.

Bennett-Lartey (1991) studied the moisture adsorption rate and the longevity of pea, sunflower and groundnut seeds using a rapid deterioration test and a storage test lasting 35 days. It was identified that RH, temperature, O_2 and CO_2 content affected seed viability during storage, where RH and temperature were the most important factors influencing seed longevity. RH affected seed quality by influencing the seed MC and the growth and reproduction of fungi and insects. At MC of between 14% and 4%, a drop of 1% in moisture doubled the storage life of the seed. Between 50°C and 0°C, a drop of 5°C doubled the life of the seed. It was found that at the same RH and temperature, pea adsorbed moisture faster than sunflower or groundnut. In the rapid deterioration test, pea deteriorated the slowest. The storage test showed that viability decreased with time in both germination and tetrazolium tests and the viability of pea was higher than groundnut or sunflower. The tetrazolium test is sometimes referred to as the "quick test" as it utilizes a chemical reaction to indicate the percentage of viable (live) seed within 24 to 48 h (Anonymous, 2005b).

Vertucci and Roos (1990) concluded that the MC at which physical and physiological changes were observed differed among different seed species, and correlated with the lipid content of the seed. Seeds with higher lipid contents had lower thresholds of respiration and lower MC for optimum storage. RH provided a better measure of the physiological level than MC at which seeds are equilibrated. They also showed that there is an optimal MC, above and below which seed vigor is depleted more rapidly during storage at 35°C.

A study by Vertucci et al. (1994) on the optimum moisture contents for storage of pea seeds illustrated that there is an optimum water content for seed storage and that, it increased with decrease in temperature. The optimum MC increased as temperature decreased. They also found that the rate of seed deterioration increased at storage RH above 50% or MC below 14%. The rate of deterioration decreased as temperature decreased for each MC studied. Seeds aged much faster when stored under light rather than in the dark. Significant deterioration was progressive with time, suggesting that aging caused it. Thus, MC and temperature did not exert independent effects, as the opposite was suggested by other researchers.

Mills and Woods (1994) studied the deterioration in seed quality of initially sound field pea (*Pisum sativum L. 'Titan'*) and white bean (*Phaseolus vulgaris L. 'Seafarer'*) during storage for 147 days at temperature-moisture levels typical of storage condition in Manitoba. In this study, the time required for development of off-odors and visible mold, fat acidity value (FAV), conductivity (seed electrolyte leakage), germination, occurrence of particular fungi and their association with off-odors and seed quality were assessed. Spoilage increased as temperature and moisture increased, as a result of changes in off-odors, FAV, conductivity and germination levels. White Bean suffered severe germination loss under less extreme conditions than field pea. There was strong association between most of the storage quality parameters studied, except for some fungi that thrived at low level in pea stored at an initial temperature of 31°C and 14.5% MC and bean at 31°C and 14.2% MC. Off-odors occurred within 63 days. No off-odors were detected after 147 days of storage for pea initially stored at 22°C and 14.5% MC or for bean stored at 22°C and 14.2% MC.

In the study of Mills and Woods (1994) the seeds tested were initially of good quality with high germination and low FAV and conductivity levels. The molds that appeared on the seeds were *Penicillium* species at low levels and *Cladosporium cladosporioides* at moderate to high levels. Seeds had shiny appearance, were mostly undamaged, and had a fresh odor. The characteristics of the seeds kept at 15°C after 147 days were similar to those at the beginning of the experiment. Among the quality parameters used, the presence of off-odors was most closely related to the onset of quality deterioration in pea and bean, because off-odors were produced by both mycological and biochemical processes during deterioration. In pea, visible molds followed the same pattern as off-odors at moderate moisture and temperature. Under cooler temperature and lower MC conditions however, mold developed slowly; under warmer and drier conditions, mold was not visible. In bean, visible molds followed the same general pattern as off-odors. With an exception, off-color occurred only at the highest temperature regimen. For all moisture contents, off-color was evident after 28 days in pea and 63 days in bean.

The most important storage fungi associated with pea and bean quality deterioration were *Penicillium* and *Eurotium* species. Other postharvest fungi isolated included *A. flavus* Link and *Rhizopus arrhizus* Fischer. In pea, *A. candidus* Link *ex Fr.* and to a lesser extent *A. ochraceus* Wilhelm and *A. wentii* Wehmer additionally occurred. The preharvest fungi *Cladosporium cladosporioides* (Fres.) de Vries and *Alternaria alternata* Keissler and bacteria occurred on both seed types (Mills and Woods, 1994).

The effect of initial temperature and initial MC investigated by Mills and Woods (1994) showed that in pea and bean, conductivity, FAV and the incidence of off-odor increased and germination decreased with increased temperature and moisture. The effect was most pronounced at 44°C for all MCs (12, 14, 16, 18 and 20) and at 31°C for higher MCs. The germination trend was more evident in bean than in pea, where germination in the control sample was only 84%. In pea, *Eurotium* appeared to peak at intermediate MCs for each temperature (10, 15, 22, 31 and 44°C), and bacteria remained generally low, except for a similar peak observed only at the two highest temperatures. *A. flavus* was more prevalent in pea than in bean, but levels were low and the effect of temperature and moisture was unclear. *Penicillium* was also more prevalent in pea rather than bean.

Mills et al. (1995) using the same procedure as Mills and Woods (1994) examined the factors affecting the cooking, physical, chemical and biological characteristics of field pea and white bean. Water uptake increased as storage temperature and initial MC increased in pea. Phytic acid content decreased with an increase in initial MC. Table 3.8 shows the number of weeks for safe storage of pea at specified grain MC and temperature.

Table 3.8 Number of weeks for safe storage of pea at specified grain MC and storage temperature (Sokhansanj and Patil, 1995)

Storage temperature (°C)	Moisture contents 12%	14%	16%	18%	21%
25	31	16	7	4	2
20	55	28	13	7	4
15	100	50	20	12	6
10	200	95	38	20	21
5	370	175	70	39	20

According to Fang et al. (1998), seed MC is the most important factor controlling physiological reactions in seeds. MC changes with RH and temperature that was proven by studying the interaction of RH and temperature at equilibrium. Cucumber, lettuce, maize, onion, pea and watermelon seeds were equilibrated over sulphuric acid (1% RH) and various saturated salt solutions (5.5% to 93% RH) at temperatures from 5 to 50°C. A complete third-order model was fitted to the data and the six best subset models (R^2 = 0.98 to 0.99) had the same functional form:

$$MC = \beta_0 + \beta_1 (RH) + \beta_2 (T) + \beta_3 (RH^2) + \beta_5 (RH)T + \beta_6 (RH)^3 + \beta_9 (RH)^2 T \qquad (3.1)$$

Where:

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_5, \beta_6, \beta_9$ = Experimental constants

RH = Relative humidity of the ambient air (%)

T = Temperature (°C)

Coefficients had essentially the same respective values among all species, except onion and pea, for which some coefficients were statistically different from those of the other species ($P \leq 0.05$). All models indicated that seed MC increased as RH increased and decreased as temperature increased; however, RH had the greater influence. The inverse relationship between seed MC and temperature, although slight, was evident in the response surfaces. The interaction effect of RH and temperature on MC was significant at $P \leq 0.001$. These results suggest that similar seed species respond similarly to temperature and RH. It was suggested that a common model could be developed and used for optimizing seed storage environments (Fang et al., 1998)

Thuy et al. (2000) studied the various drying methods and storage conditions for pea. Seed germination and conductivity, a measure of seed vigor, was used to find differences between natural sun drying, natural ventilation and artificial drying at 30°C and 45°C. They tested MC, germination, conductivity and percentage of hollow heart for seeds with MC initially at 10% after 20, 40 and 60 d at storage conditions of 25°C and 90% RH and 20.5°C and 55% RH. Germination was not significantly affected by drying method and seed dried at 30°C had a lower conductivity than seed dried at 45°C. Germination was reduced after 40 to 60 d of storage. Conductivity increased slightly after 40 days in open storage and increased significantly throughout closed storage.

Booth et al. (2001) showed that storage conditions at temperatures of 30°C and above combined with relative humidity of 80% or higher, limited the storage life of whole sound pea to less than 100 mold-free days. This was also true at humidities of 85-90% or higher, at all temperatures (10, 20, 30 and 40°C) studied. Experiments with feed pea mixtures, although limited in duration, showed similar trends, with increased hygroscopicity of the damaged pea and foreign material-contaminated samples making them even more susceptible to molding. McKay et al. (2003) showed that pea at 18% moisture could be stored for 20 weeks at 20°C, but only for 4 weeks at 25°C.

3.5 Summary

Delay in pea harvest affects postharvest breakage more than seed MC. Handling characteristics improve in field pea stored at higher MC (Cassel and Green, 1982). High RH promotes deterioration and causes a change in the protein of pea (Gorecki et al., 1985). Seed coat breakage increases with the decrease in MC and in most cases, it increases with a decrease in temperature (Ehiwe et al., 1987). Seeds with higher lipid contents had lower levels of respiration and lower MC for optimum storage. RH provided a better measure of the physiological level than MC at which seeds are equilibrated. There is an optimal MC, above and below which seed vigor is depleted more rapidly during storage at 35°C (Vertucci and Roos, 1990). RH and temperature are the most important factors affecting seed longevity (Bennett-Lartey, 1991). Optimum MC for seed storage increases with a decrease in temperature and the rate of deterioration decreases with a decline in temperature and it increases at RH above 50% or MC below 14% (Vertucci et al., 1994).

Spoilage in pea increases with increase in MC and temperature. Pea could be stored for 147 days at 15°C without any changes in quality. The presence of off-odors is related to the deterioration of pea produced by mycological and biochemical processes during storage. Visible molds in stored pea follow the same pattern as off-odors at moderate moisture and temperature. Under cooler temperature and lower moisture condition, molds develop slowly; under warmer, dryer condition molds are not visible. Storage fungi such as *Penicillium spp., Eurotium spp., Aspergillus flavus* Link*, and Rhizopus* fischer have been identified in pea and bean*.* *A. candidus* and to a lesser extent, *A. ochraceus* Vilhelm and *A. wentii* Wehmer also were found in pea. Preharvest fungi have been also identified such as *Cladosporium cladosporioides, Alternaria alternata* Keissler and bacteria (Mills and Woods, 1994).

Water uptake in pea increases as storage temperature and MC increase (Mills et al., 1995). Seed MC is the most important factor controlling physiological reactions and it changes with RH and temperature. Seed MC increases as RH increases; MC decreases as temperature increases, however, RH has greater influence (Fang et al. 1998).

Storage condition at temperatures above 30°C and RH above 80% limit the storage life of the whole sound pea to less than 100 mold-free days. This is also true for humidities above 85-90% at temperatures of 10, 20, 30 and 40°C. Feed-grade pea is even more susceptible to molding because it contains more damaged seeds and foreign material (Booth et al. 2001).

Many studies have been conducted on pea storage but no study was conducted on feed-grade pea and none of them is on safe storage of this commodity. The work by Booth et al. (2001) is an exception to this, although the first experiment done by them was very limited in time, which did not really reveal the number of mold-free days for feed-grade pea in simulated tropical conditions. The second experiment showed even a higher number of mold-free days for feed-grade pea compared to whole sound pea, which did not explain the presence of foreign material in feed-grade pea. No model was developed for the data and no spoilage index was created for mold development; mold species were not identified in their study.

3. OBJECTIVES

Field pea exports to countries with tropical climates are at particular risk due to rapid loss of quality. Higher temperatures and humidity promote mold growth, and the damaged kernels (more than 10% split, broken or shrivelled) and relatively large amounts of FM (up to 6%) in feed pea may block airflow making it susceptible to moisture accumulation and molding. It is therefore important to develop practical strategies for safe storage of feed pea. Knowledge on the moisture adsorption characteristics of pea stored in adverse storage conditions is important in the transportation and storage of this export commodity.

The main objective of this research project is to determine safe storage conditions for Canadian produced and exported feed pea when stored under high humidity and temperature conditions such as those prevailing in tropical and subtropical regions of the world. Tropical storage conditions were simulated by storing samples of both whole sound and feed-grade pea at temperatures of 10, 20, 30 and 40°C and RH of 60, 70, 80, and 90%. The specific objectives are:

a) to determine the number of mold-free days for clean pea and typical feed pea subjected to the aforementioned storage conditions. The purpose of this objective was to examine how the grade of pea affects the appearance of visible mold on the samples stored at various conditions of temperature and RH;
b) to determine the effect of feed pea components on molding. As typical feed-grade pea is composed of different components, it was thought that if it is known which

component is more likely to deteriorate first, the quality of feed-grade pea could be improved to increase the shelf life of this commodity;

c) to identify genus of molds and examine their potential toxicity. Feed pea is consumed by animals so, it is very important to know if consumption of this product is hazardous in case of deterioration and molding; and,

d) to model mold development under adverse storage conditions. The purpose of this objective was to develop a model based on number of mold free days of both feed and whole sound pea. This model could be used by using the temperature and RH of the storage environment to predict how many days a batch of pea could stay mold free at specified condition of temperature and RH.

4. MATERIALS AND METHODS

Finding the number of mold-free days for both whole sound pea and feed-grade pea took most of the time in the experimental phase of this research. This was an important phase conducted in order to both identify mold species and assess a model that can predict the number of mold-free days of pea samples in storage and during shipment, which has not been previously undertaken.

4.1 Material

A 15 kg sample of No. 1 Canada ‘Mozart’ field pea was obtained from Walker Seeds Ltd. of Tisdale, SK. The seeds were sieved and hand-sorted for quality. Qualities such as smoothness, roundness and an intact seed coat were used to sort pea. Only good quality whole pea were used in this experiment. This is referred in the experiment as clean pea.

The sample of feed pea was mixed by hand using whole yellow and green peas and pea screenings also obtained from Walker Seeds Ltd. According to the analysis done by Booth et al. (2001), a feed-grade pea sample contains 54.1% whole yellow pea, 2.0% foreign materials, 0.9% cracked seed coats (yellow), and 5.1% whole pea of other color (green), 0.4% cracked seed coats (green), 13.8% splits (yellow), 4.8% splits (green), 7.3% shriveled (yellow), 4.8% shriveled (green), 3.0% other damage (yellow), 0.1% other damage (green), 1.9% small (yellow) and 1.8% small (green). Other damaged yellow and green peas are referred to any damage other than splits, insect damage, heated or shriveled. In other word any discoloration or physical damage on the face of the cotyledon is referred as other damaged pea (Canadian Grain Commission, 2003). Typical feed-grade pea samples were assembled to reflect these ratios. For the storage studies, 10 g of sample was spread in one layer on the petri dishes; eight petri dishes were placed in each airtight chamber; four on each shelf (as shown in Figure 4.1). The amount and percentage of each of the grade factors in a 10 g sample are shown in Table 4.1. Photographs of both feed-grade and clean pea samples are shown in Figures 4.2 and 4.3.

Figure 4.1 Petri dishes arrangement on the shelves.

Table 4.1 Typical compositions of pea samples by grade factors (Booth et al., 2001).

Grade factor	Amount (g)	Percentage (%)
Whole yellow	5.4	54.0
Foreign material	0.2	2.0
Cracked seed coat	0.1	1.0
Damaged		
Splits	1.9	19.0
Shriveled	1.2	12.0
Other damage	0.3	3.0
Small seeds (yellow and green)	0.4	4.0
Peas of other color (green)	0.5	5.0
Total	10.0	100.0

Figure 4.2 Sample of whole yellow pea.

Figure 4.3 Sample of feed-grade pea.

4.2 Experimental Equipment

Airtight cylindrical chambers were used for storage experiments in this research. These chambers were then placed in controlled temperature cabinets that are described in the following sections.

4.2.1 Airtight chamber

Forty-eight airtight cylindrical chambers were designed and built to provide controlled environment for pea storage. They were made of PVC pipe, with clear acrylic end plates and two shelves to hold the petri dishes. The interior dimensions were 190 mm × 205 mm. The two round shelves were joined together with a bolt placed on a stand constructed of a PVC pipe end cap. The cap had a large hole drilled out of the top and six small holes drilled around the outer edge in order for the air to circulate easily throughout the container. The top support tray was made of acrylic or pexiglass in order to increase visibility through to the second shelf of samples. Figure 4.4 shows the components of the airtight chamber. The top of the support trays had fishing line tied to it, as well as a fishing leader. The leader was used to suspend the shelves from the bottom of the scale in order to measure weight without disrupting the samples, nor the storage environment. A glass dish containing the solution to control the humidity levels was placed at the bottom of the test chamber. Eight 60 mm × 15 mm plastic petri dishes were placed on the shelves in each airtight chamber. The clear acrylic end plate was fastened with five wing nuts, two rubber washers were used, one at the bottom and the other, at the top of the chamber, to help provide airtight condition. Rubber stoppers were used to close the access holes on the top acrylic plate in order to provide airtight condition inside the chamber.

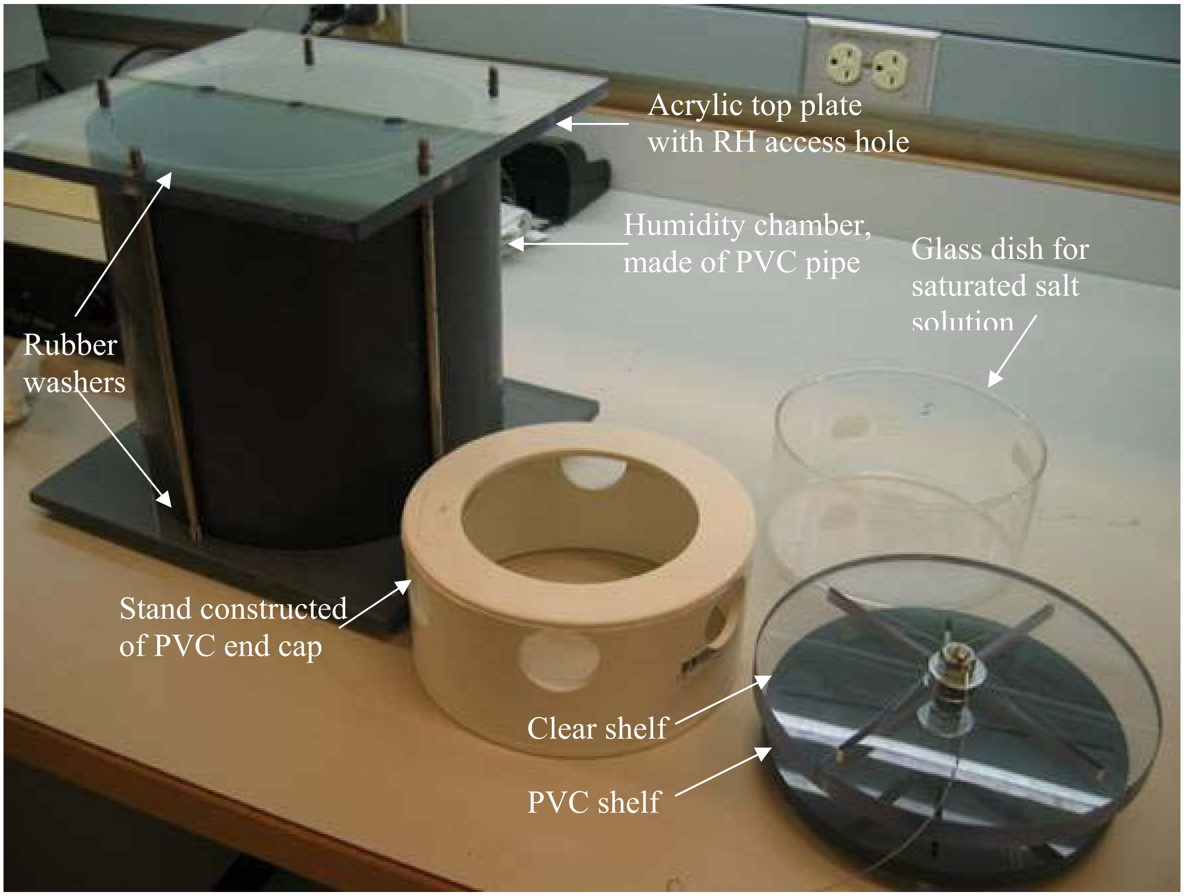


Figure 4.4 Different components of airtight chambers.

4.2.2 Controlled environment cabinet

Four controlled environment cabinets (Conviron Plant Growth Chamber PGR15, Controlled Environment Ltd., Winnipeg, MB) at the Phytotron facilities of the College of Agriculture, University of Saskatchewan were used for each temperature setting for storage and moisture adsorption test in static environment. After a day of temperature stabilization, 16 airtight chambers were placed inside the cabinets at 10 and 20°C and 8 airtight chambers inside the cabinets at 30 and 40°C (Figure 4.5). As the number of airtight chambers was less than the required, 8 chambers were located in each Conviron chamber, four at each RH of 80 and 90%. It was apparent that these samples will become molded in less than 2 months and then the experiment could carry on by changing the RH inside the airtight chambers to 60 and 70%. This allowed for the testing of four humidity levels at each temperature in duplicate for both whole pea and feed-grade pea.

Figure 4.5 Controlled environment chamber.

For moisture adsorption in dynamic environment two chambers, namely; Angelantoni environmental chamber (ACS, Massa Martana, Italy) and the cabinet of thin layer dryer (B-M-A, Inc. Ayer, MA) were used to examine the moisture adsorption of field pea as a function of temperature and RH. Both temperature and RH were controlled inside the chambers. The air velocity was determined to vary between 0.25 and 0.4 m/s inside the Angelantoni environmental chamber. The cabinet of thin layer dryer was closed from the thin layer tunnel in order to prevent moisture condensation inside the tunnel, but there was still air circulation inside this chamber as the fan was running. The air velocity was similar to the air velocity inside the Angelantoni chamber (0.25-0.4 m/s). Both feed-grade and whole sound peas were placed inside these chambers after temperature and RH stabilization each in three replication in aluminum dishes. Figures 4.6 and 4.7 show the Angelantoni and the cabinet of thin layer dryer respectively.

Figure 4.6 Angelantoni environmental chamber.

4.3 Protocols and Methods

The research consisted of two laboratory experiments. The first experiment was a two-month study, conducted to develop a time-dependent model of pea moisture adsorption as a function of ambient temperature and RH in dynamic environment. The second experiment was a seven-month study of both feed pea and whole sound pea, which was done to model mold-free days as a function of storage temperature and RH and to identify mold species and their potential toxicity in static environment.

Figure 4.7 The environmental chamber of the thin layer dryer.

Protocols and methods were required to ensure that the data could be managed and that consistency was maintained throughout the course of data collection and analysis. These included experimental plan, maintenance of RH inside the chamber, RH measurement, weighing of the samples, measuring the amount of CO_2 inside the chamber, moisture content determination and fungi identification protocol.

4.3.1 Experimental plan for storage test in the static environment

As in any classification problem, an adequate number of samples were required relative to the number of features used in order to have confidence in the results. A balance had to be established between having a realistic number of features, an adequate level of statistical power in the data, and a number of samples that could be reasonably collected.

The variability in the composition and quality of feed pea makes it difficult to determine how individual variables such as temperature, RH and FM affect mold development. Therefore, tests were conducted on both pea of a common commercial variety of No. 1 Canada to eliminate as many variables as possible and typical feed-grade pea as well as feed pea components to isolate the variables that impact mold development. The results from No. 1 Canada were used as a standard against the other sample. This data was then used to determine the effect of temperature and RH on both MC and mold growth.

For storage study of pea under static environment, both whole sound and feed-grade peas were stored under temperatures of 10, 20, 30 and 40°C and humidities of 60, 70, 80 and 90%, each in duplicate in airtight chambers. The experimental plan for this study is shown in Table 4.2. In preliminary experimental trials, all components of feed-grade pea were exposed to the temperature of 40ºC and RH of 90% in airtight chambers, in order to determine the effect of each component on mold appearance.

Table 4.2 Experimental plan for storage and moisture adsorption study in static and dynamic environment.

Variable	Level	Number
Type of pea	Whole sound, Feed-grade	2
Temperature	10, 20, 30, 40°C	4
Relative Humidity	60, 70, 80, 90%	4
No. of Treatments		32
No. of Replicates for static environment		2
No. of Replicates for dynamic environment		3
No. of Runs/ experiment for static environment		64
No. of Runs/ experiment for dynamic environment		96

4.3.2 Moisture adsorption of pea in dynamic environment

Moisture adsorption of pea in dynamic environment was performed on both samples of whole sound 'Mozart' pea obtained from Horizon Seed Processors in Aberdeen, SK. and feed-grade pea obtained of its various components (yellow whole, green splits, foreign material, etc.). The samples were placed in an environmental chamber and the cabinet of thin layer dryer to examine the moisture adsorption of field pea as a function of temperature and RH, and find an equation to predict moisture adsorption of pea after specified time in a dynamic environment. Samples of both clean and feed-grade peas were exposed to a specific combination of RH (60, 70, 80 and 90%) and temperature (10, 20, 30, and 40°C) that was adjusted inside these chambers until equilibrium moisture content. Air velocity varied from 0.25 to 0.4 inside the environmental chamber. Three replicated tests were conducted to gather more data for each temperature-RH combination. The experimental plan for this test is given in Table 4.2. It took around 42 to 209 h for feed-grade pea and 31 to 208 h for whole sound pea to equilibrate in different conditions of temperature and RH. During this period, the mass of sample was recorded to determine the moisture change with respect to time.

The Peleg model (Spoda et al., 1994; Hung et al., 1993; Turhan et al., 2002) was used in describing the change in moisture content and four different models, namely exponential (Brooker et al., 1992; Bala, 1997), Page (Brooker et al., 1992; Bala, 1997), diffusion (Bala, 1997) and two-term exponential (Sokhansanj and Patil, 1996) models were used to describe moisture ratio of the samples with respect to time.

1. Peleg model:

$$M = M_i + \frac{t}{k_1 + k_2 t} \tag{4.1}$$

where:

M = moisture content at any time (% d.b.)

M_i = initial moisture content (% d.b.)

t = time (h)

k_1 = Peleg rate (h%$^{-1}$)

k_2 = Peleg capacity constant (%$^{-1}$)

2. Exponential model:

$$\frac{M - M_e}{M_i - M_e} = e^{(-kt)} \tag{4.2}$$

where:

M_e = equilibrium moisture content (% d.b.)

k = experimentally determined constant (min^{-1})

t = time (min)

3. Page model:

$$\frac{M - M_e}{M_i - M_e} = e^{-kt^N} \tag{4.3}$$

where:

k, N= experimentally determined constants

4. Diffusion model:

$$\frac{M - M_e}{M_i - M_e} = Be^{(-At)} \tag{4.4}$$

where:

A, B = experimentally determined constants

5. Two-term exponential model:

$$\frac{M - M_e}{M_i - M_e} = A_0 e^{(-k_1 t)} + A_1 e^{(-k_2 t)} \tag{4.5}$$

where:

A_o, A_1, k_1, k_2 = experimentally determined constants

4.3.3 Relative humidity measurement in static environment

The RH within the airtight chambers was measured once a week using a Vaisala HM 34 solid-state humidity and temperature sensor (Vaisala Inc., Woburn, MA). A hole with a rubber stopper was located on the top of each chamber for the insertion of the humidity and temperature sensor. Figure 4.8 shows how the humidity within the airtight chamber was measured.

The precision of the Vaisala sensor for RH was specified by the manufacturer as ±2% over a range of 0 to 90%. This calibration was checked by using a RH generator. This device generates humidity in a small chamber; humidity was set at 50, 60, 70, 80, 90 and 95% at a time in order to calibrate the Vaisala in the range of 50 to 95%. The unit showed a negative error of 1% at 90% RH and positive errors of 1.1% at 80% RH; 2% at 70% RH and +4% at 60% RH. These deviations were within the general accuracy specified or known for RH sensor except for 60%.

Figure 4.8 Measuring of the RH within the airtight chamber.

4.3.4 Maintenance of relative humidity inside the airtight chambers

A glass dish containing 200 ml saturated salt solution or dilute sulphuric acid solution was placed at the bottom of each test chamber in order to control RH levels inside the containers during storage studies in the static environment. The sulphuric acid concentrations and the salts that were used are provided in Table 4.3. RH of 60, 70, 80 and 90% were created by saturated salt solutions in airtight chambers at temperatures of 10, 20 and 30°C, while the same range of humidity was provided by dilute sulphuric acid solutions at 40°C in airtight chambers. The four RH levels at each temperature for both whole and feed-grade peas were tested in duplicate. RH was let to be stabilized for approximately one week before placing samples inside the chambers. The solutions controlling the humidity were checked weekly.

Table 4.3 Saturated salt and dilute sulfuric acid solutions used in the experiments (Bala, 1997; Rahman, 1995; Booth et al., 2001).

	Target RH			
Temperature	60%	70%	80%	90%
10°C	NaBr	$CH_3CO_2Li.2H_2O$	K_2CrO_4	$Sr(No_3)_2$&H_2SO_4
20°C	NaBr	$SrCl_2$	$(NH_4)_2SO_4$	KNO_3
30°C	NaBr	$SrCl_2$	$(NH_4)_2SO_4$	KNO_3
40°C	H_2SO_4 (25.9%)	H_2SO_4 (21.4%)	H_2SO_4 (16.9%)	H_2SO_4 (12.5%)

It was difficult to maintain constant RH during the entire experiment, especially during the initial stages when pea samples were placed in the test chamber. The samples adsorbed or desorbed moisture depending upon the RH and thus, increased or decreased the RH of the headspace in the test chamber. The RH in the headspace built up to its initial value in about 100 days when the storage temperature was low and RH was high

(10°C, 90% RH). It took more than 40 days at 20°C and 90% RH for the headspace RH to build up and samples already had gone molded. But it only took about 15 days for RH to stabilize at high temperature and high RH (30 and 40°C, 80 and 90% RH).

Achieving a 90% RH in the chambers at all temperatures was difficult; at 40°C, the humidity could be controlled by adding water in order to increase the RH or adding acid, in order to decrease the RH to desired level. At other temperatures where RH was controlled by salt solutions, there was no way to control the RH rather than change the type of salt. At 10°C, the salt solution was changed once to achieve 60% RH and twice to achieve the 90% RH. The problem at 90% RH was that at initial stage of the experiment, there was a dramatic decline in RH. The samples went molded before RH increased to its initial condition; this is the reason for low mean RH at 90% level. Mean RH data are presented in Appendix A (Table A.19).

4.3.5 Weighing of the samples in static environment

Weight of the samples was recorded once a week in order to measure their MC. This was done by removing a rubber stopper at the top of the lid and running a fishing leader to a hook at the bottom of a scale (Mettler PL1200, Mettler Instrumental, CH-8606, Greifensee, Zurich, Switzerland) with 0.01 accuracy as shown in Figure 4.9. The weights were taken this way to minimize the disruption of the samples and environment in the container, i.e., the RH. There is a possible error in weighing the samples especially at high RH, because of the moisture condensation on the bottom of the lower shelf that could not be observed because chambers were closed during the entire storage time. This moisture condensation was observed in some samples at high RH after they became moldy and chambers were opened to remove the samples and terminate the experiment.

This error could not be measured, as we do not know when the moisture condensation has occurred or if it has occurred at all. No condensation was observed on the shelves' surface or in petri dishes or even on the interior chamber surface.

Figure 4.9 Weighing the samples inside the airtight chamber.

As weight of the samples was measured with the shelves during the experiment, shelves were weighed at the beginning of the experiment. The data collected from weighing the samples were then converted to moisture content data using the following equations, Dry weight of sample was calculated by having initial MC and initial weight of the sample:

$$\mathrm{DW} = \mathrm{W_i} \times (1 - \mathrm{M_i}) \tag{4.6}$$

where:

DW = dry weight of the sample (g)

W_i = initial weight of the sample (g)

M_i = initial moisture content (% w.b.)

$$M = \frac{W - DW}{W} \text{ x } 100\% \tag{4.7}$$

where:

M = moisture content at any time (% w.b.)

W = weight of the sample at any time (g)

DW = dry weight of the sample (g)

MC in dry basis was calculated by having the MC at any time in wet basis. It was necessary to have MC in dry basis in order to do the latter calculations.

$$M_d = \frac{M_w}{1 - M_w} \tag{4.8}$$

where:

M_d = moisture content in dry basis

M_w = moisture content in wet basis

Then the moisture content data and time at which these data were collected were used to determine the moisture adsorption characteristics of field pea (whole sound and feed-grade) under static environment.

4.3.6 Measurement of CO_2 inside the chamber

It was thought that if the containers were completely sealed to the outside environment, the air in the chamber would have an increase in the CO_2 content resulting in mold growth retardation or inhibition on the samples. Therefore, CO_2 content was tested every two to three weeks by removing some of the container air using a syringe from the hole with the rubber stopper, limiting the disturbance of the samples (Figure 4.10). Gas samples were analyzed for CO_2 using a gas chromatograph at the Department of Soil Science of the College of Agriculture, University of Saskatchewan. CO_2 concentration was high in contaminated samples, showing molds' respiration.

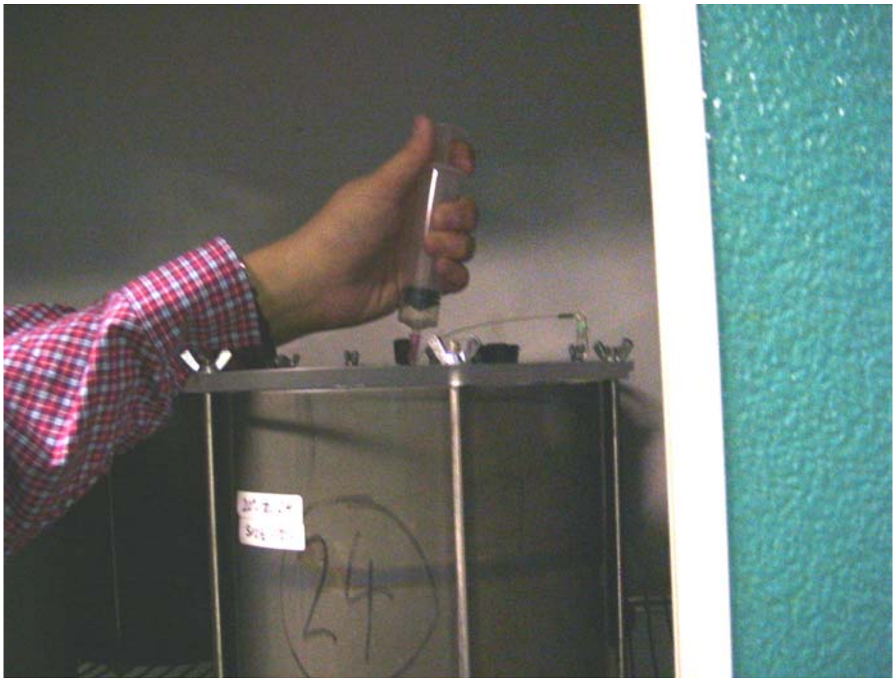


Figure 4.10 Taking CO_2 sample by inserting a 20 mm syringe beside the rubber stopper.

Carbon dioxide concentration inside the test chambers was measured every 2 to 3 weeks. The results are tabulated in Appendix B. The amount of CO_2 (ppm) inside the test chambers was almost the same as the ambient CO_2 during the experiment at all the temperatures and RH of 60 and 70% and also at 10°C and 80% RH. The CO_2 concentration inside other samples varied within the range of normal CO_2 variation in the air. The amount of CO_2 had doubled or in some cases, had tripled after 50 days at temperature of 20°C and 80% RH, after 30 days at temperature of 30°C and RH of 80% and after 20 days of storage at 40°C and 80% RH. The CO_2 concentration inside the chambers at 10°C and 90% RH was 10 times more than ambient CO_2 after 90 days of storage. At 20°C and 90% RH, CO_2 had doubled at the time samples were molded. The CO_2 concentration inside the chambers at 30°C and 90% RH was 10 times more than ambient CO_2 for feed-grade pea at the time that samples were molded, but only doubled for clean pea, 6 days before removing the samples from the storage environment. The CO_2 concentration had dramatically increased, 100 times the ambient CO_2 concentration, at 40°C and 90% RH at the time samples were molded, which can be explained by the high respiration activity of the fungi.

4.3.7 Moisture content measurement

The initial MC of the whole pea, feed-grade pea, and all components of feed-grade pea was determined using standard S352.2 of the American Society of Agricultural Engineers (ASAE, 2003) and standard 44-15A of the American Association of Cereal Chemists (AACC, 1995). The MC of pea at which molds started to appear was calculated based upon the weight of the samples and its initial MC, and it was also determined by AACC standard 44-15A method. The scale used measured the mass of the samples to a minimum of two decimal places, which was adequate resolution to compensate for the sample size in this case. The dishes had snugly fitting lids and were made of aluminum.

The mass of the pea and drying dishes was recorded prior to drying the samples at 103°C for 72 h, or 130°C for 1 h. The lids were open during this time. At the end of the drying period, the lids were closed and the dishes were placed in a desiccator to cool to room temperature. The dried and cooled samples were weighed with the dish, and the mass of each empty dish with its lid was recorded. This allowed the calculation of the pea initial and final MC using:

$$\mathrm{MC} = \frac{\mathrm{PD} - \mathrm{DPD}}{\mathrm{PD} - \mathrm{D}} \times 100\%, \tag{4.9}$$

where:

MC = pea moisture content (%w.b.),

PD = mass of pea plus the dish (g),

DPD = mass of dry pea plus the dish (g), and

D = mass of the dish (g).

4.3.8 Fungi identification

Samples were examined for mold appearance every day and as soon as mold was observed, the contaminated samples were removed from the chambers. The contaminated petri dishes of samples were photographed and then sent for mold identification to Discovery Seed Labs, Ltd. of Saskatoon, SK. Samples were divided to three categories: (a) foreign materials, e.g. broken seeds, stem pieces, etc. (not present in all samples); (b) whole seeds; and (c) whole seeds that were surface sterilized before plating. Surface sterilization was done by the method usually applied at seed testing labs in detection and enumeration of seed-borne pathogens, i.e. immersion in 33% Javex (2% NaOCl) for 2 min and draining before plating. The pieces of material were plated on potato dextrose agar containing streptomycin and ampicillin. Only four pieces of each category of material were plated per sample. The four pieces were all plated in the same petri dish. The plates were incubated under a mixture of fluorescent and near UV light for 6-8 days at room temperature before assessment. Two contaminated samples are shown in Figures 4.11 and 4.12.

Figure 4.11 Feed-grade pea molded at 40°C and 90% RH.

Figure 4.12 Whole sound pea molded at 40°C and 90%RH.

A rough identification of the fungi that grew from the material was made according to cultural appearance and by microscopic examination of their sporulating structures. In addition, a crude estimate of the extent of fungal growth from the material was made.

4.4 Data Analysis and Processing

Data were imported to an Microsoft Excel (Microsoft Corp., Redmond, WA) worksheet; these data included the weight of the samples, RH inside the chamber, initial and final MC, the amount of CO_2 and the date at which mold appeared on the samples.

4.4.1 Moisture ratio determination

Moisture ratio was determined in order to compare each set of data, e.g., pea at 10°C and different humilities of 60, 70, 80 and 90%. Moisture ratio was calculated using following equation:

$$\mathrm{MR} = \frac{\mathrm{M} - \mathrm{M_e}}{\mathrm{M_i} - \mathrm{M_e}} \tag{4.10}$$

where:

MR = moisture ratio

M = moisture at any time (% d.b.)

M_e = equilibrium MC (% d.b.)

M_i = initial MC (% d.b.)

M_e in above equation was estimated by SAS (The SAS Institute Inc., Cary, NC) from fitting the exponential model to experimental data for static environment. As M_e was an estimated value, instead of giving a moisture ratio between 0 and 1, in some cases moisture ratio was lower than zero.

4.4.2 Statistical analysis

The SAS software package was used to fit the exponential model into each set of temperature and RH data. Data from both replications in static environment and the three replications in dynamic environment were mixed in order to increase the confidentiality of experimental data. Parameters M_e and k were estimated by SAS as the model constants for static environment. As we did not have the M_e in static environment, it was considered as a parameter to be estimated. The parameter k was estimated by SAS for dynamic environment while M_e was experimentally obtained in dynamic environment.

$$M = M_e + \left[(M_i - M_e)\, e^{-kt}\right], \tag{4.11}$$

where:

M = moisture at any time (% d.b.)

M_i = initial moisture content (% d.b.)

M_e = equilibrium moisture content (% d.b.)

k = exponential constant

t = time (min)

The ‘Regression’ function of Data Analysis in Microsoft Excel was used to determine the R^2 and MSE in order to compare the experimental MC with calculated MC, as these values cannot be obtained by SAS. The Solver from Microsoft Excel was then used to determine the relationship between experimental constants (k and M_e) with temperature and RH of the environmental chamber.

4.4.3 Model development

A model was identified to fit the mold-free days data, in order to predict mold development in storage after specified time. This model is similar to the model suggested by Khoshtaghaza et al. (1999) to estimate the number of days until the development of visible mold growth in alfalfa cubes:

$$Y = 10^{(a - b\,T - c\,RH)} \tag{4.12}$$

where:

Y = storage time (d)

T = temperature (°C)

RH = relative humidity (%)

a, b, c = constants

Equation 4.12 is valid for tested ranges of 16 to 39°C and 70 to 85% RH up to 90 days for alfalfa cube storage. A spoilage index (SI) was also indicated by Khoshtaghaza et al. (1999) as follows:

$$SI = \sum_{i=1}^{n} \left(\frac{\Delta t}{Y}\right)_i \tag{4.13}$$

where:

Δt = time interval (d)

In equation 4.13, Y is the storage time (d) to molding calculated from equation 4.12 using temperature, and RH at time t. Δt is the time interval during which the temperature and humidity are constant. Index i represents each data set at time t; n represents the total number of data ($t = n\,\Delta t$). When $SI \geq 1$, the model indicated that cubes in the container were moldy. For sure there are a number of uncertainties in these calculations.

SI index in this study is calculated only as a demonstration on how it can be used to determine the onset of mold development for pea samples during storage and transport. For SI index to be accurate another storage study has to be conducted for data verification, where in RH and temperature will be measured at close intervals, i.e., every day or every half a day.

The Solver from Microsoft Excel was used to identify mold free days model for both clean and feed-grade peas at temperatures of 10, 20, 30 and 40°C and RH of 80 and 90%. The same program was used to identify a spoilage index for both feed pea and clean pea.

5. RESULTS AND DISCUSSION

In order to fulfill the objectives of this research, the collected data were analyzed and the results of this analysis are discussed in the order of fulfillment. These are: a) moisture adsorption of pea in a dynamic environment; b) moisture adsorption of pea and its components during storage in static environment; c) fungi identification; and d) mold-free days.

5.1 Moisture Adsorption of Pea in a Dynamic Environment

A number of models expressing moisture adsorption of pea as a function of temperature and RH were presented in Chapter 4. Most of these models are exponential in terms of time. The data in moisture adsorption in dynamic environment is taken from the experiment on both feed-grade and clean peas that was conducted in the environmental chambers with air velocity of 0.25 to 0.4; weight of the sample was taken in specified time intervals until equilibrium. Among the models, the Page model (equation 4.3) was chosen to be compared with the Peleg model (equation 4.1) as it had the highest R^2 value and the smallest mean square error (MSE) in almost all sets of data. Between the Page and the Peleg model, the former fitted almost all sets of data better than the latter. But the problem with the Page model was that the model parameter could not be expressed as a function of temperature and RH. As a result of moisture adsorption in dynamic environment, the exponential model (equation 4.2) was determined to be used as an appropriate model to describe moisture adsorption as a function of temperature and RH during storage, as it had high R^2 and small MSE values; model parameter could be better expressed as a function of temperature and RH than the Page model. Figure 5.1

shows a typical fit of four models, namely exponential, page, diffusion and two term exponential model to clean and feed-grade pea. Parameter estimates of the exponential model are listed in Table 5.1 and 5.2; parameter estimates for the rest of models are presented in Appendix A.

The constants of the exponential model are functions of temperature and RH as it is shown in the following equations. For clean pea,

$$k = 0.03 - 0.06\ RH - 0.0001\ T + 0.03\ RH^2 + 0.0002\ RH\ T \qquad (5.1)$$

with R^2 value of 0.82, MSE of 1.23×10^{-7} and a random residual distribution (ANOVA table is presented at the Appendix D).

where:

k = exponential constant (min^{-1})

T = temperature (°C) and;

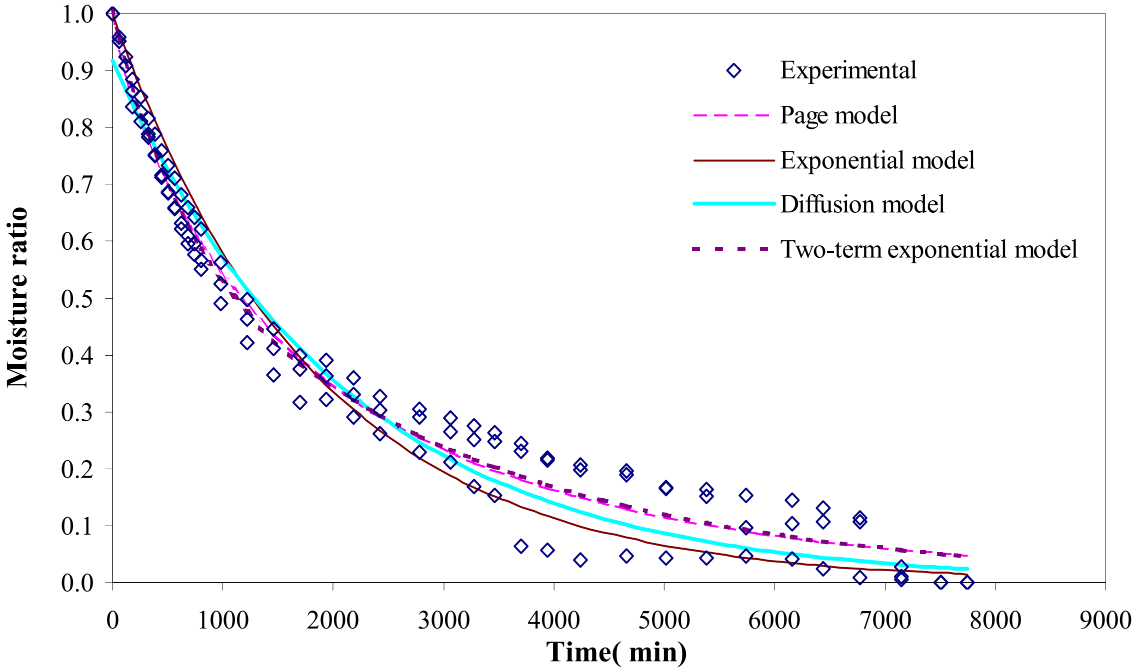
RH = relative humidity (decimal)

For feed-grade pea,

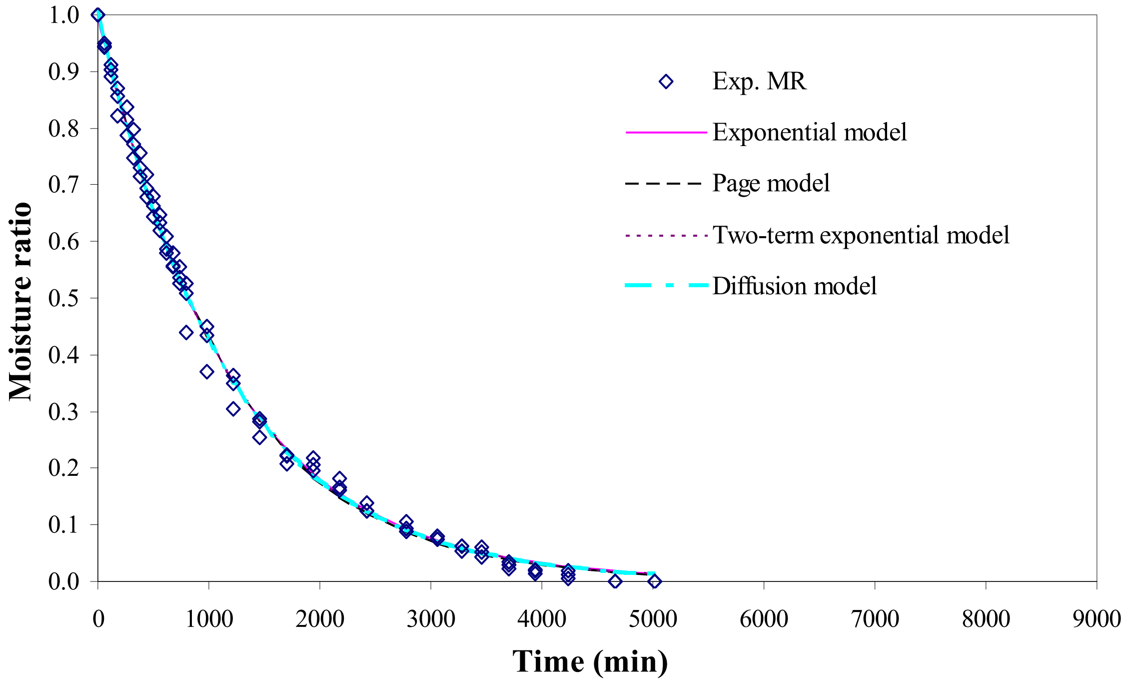
$$k = 0.0003 + 0.003\ RH + 3.6 \times 10^{-5}\ T - 0.005\ RH^2 + 7.4 \times 10^{-5}\ RH\ T \qquad (5.2)$$

with R^2 value of 0.77 and MSE of 3.04×10^{-8} and a random residual distribution (ANOVA table is presented at the Appendix D).

The above analysis shows that coefficient k is significantly dependent on the temperature and RH of storage. RH has a larger impact on k value than temperature of the storage environment. The value of k increased at higher temperatures and it was higher at lower RH within one temperature setting.



a) Clean pea



b) Feed pea

Figure 5.1 Fit of four moisture adsorption models to the experimental data for clean and feed peas at T=40°C, RH= 90%.

Table 5.1 Values of k and M_e obtained from non-linear regression analysis and from the experiment respectively for feed-grade pea.

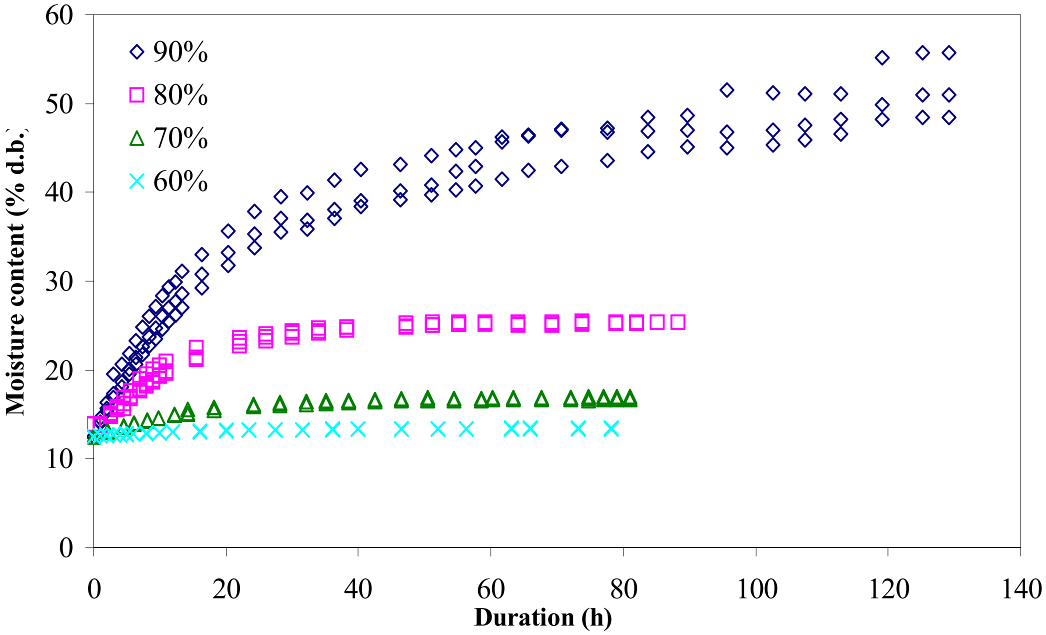
Temperature (^oC)	RH (%)	k (min^{-1})	M_e (% d.b.)	R^2	Standard error of estimate
10	60	0.0007	14.13	0.963	0.0625
10	70	0.0010	15.58	0.965	0.0613
10	80	0.0002	19.74	0.974	0.0558
10	90	0.0002	23.81	0.959	0.0606
20	60	0.0009	14.24	0.956	0.0601
20	70	0.0010	16.56	0.970	0.0596
20	80	0.0003	28.50	0.982	0.0446
20	90	0.0003	21.82	0.932	0.0852
30	60	0.0011	14.80	0.979	0.0465
30	70	0.0008	19.85	0.992	0.0284
30	80	0.0008	27.15	0.998	0.0139
30	90	0.0006	48.40	0.983	0.0475
40	60	0.0010	17.17	0.989	0.0320
40	70	0.0012	19.94	0.962	0.0550
40	80	0.0013	28.76	0.984	0.0426
40	90	0.0009	49.23	0.997	0.0183

The experimentally obtained moisture adsorption curves up to 90 h for both clean and feed pea at 40°C are presented in Figure 5.2. The data shows that the moisture adsorption rates were the highest during the initial stages and gradually decreased as the MC approached equilibrium. Moisture ratio of both whole sound and feed-grade peas exhibits the expected reverse sigmoidal shape for agricultural products.

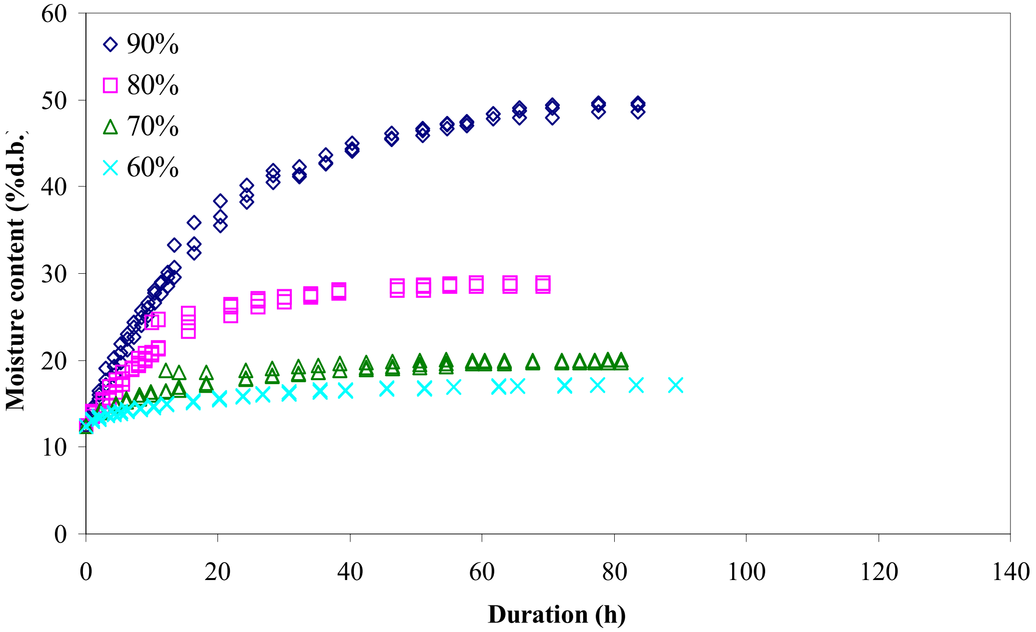
Table 5.2 Values of k and M_e obtained from non-linear regression analysis and from the experiment respectively for clean pea.

Temperature (^oC)	RH (%)	k (min^{-1})	M_e (% d.b.)	R^2	Standard error of estimate
10	60	0.0000	12.40	0.000	0.0000
10	70	0.0008	13.93	0.956	0.0756
10	80	0.0002	16.81	0.976	0.0612
10	90	0.0003	19.72	0.993	0.0263
20	60	0.0027	12.59	0.865	0.1215
20	70	0.0007	14.30	0.938	0.0946
20	80	0.0004	24.78	0.993	0.0320
20	90	0.0003	18.06	0.976	0.0576
30	60	0.0028	13.02	0.845	0.1560
30	70	0.0007	17.69	0.998	0.0163
30	80	0.0008	24.29	0.998	0.0150
30	90	0.0006	45.66	0.993	0.0321
40	60	0.0014	13.38	0.989	0.0340
40	70	0.0011	16.80	0.994	0.0230
40	80	0.0012	25.32	0.991	0.0340
40	90	0.0005	50.12	0.972	0.0509

* Data at this temperature, humidity setting is not available due to observing no change during the experiment.



a) Clean pea



b) Feed pea

Figure 5.2 Moisture content of clean and feed-grade peas during storage at 40°C and RH of 60, 70, 80 and 90%.

5.2 Moisture Adsorption of Pea and Components During Storage in Static Environment

The static environment is defined as the environment with no air circulation. The initial MC of pea and its components are shown in Table 5.3. Mean MC ranged from 7.38% w.b. for split green pea to 10.35% w.b. for whole sound yellow pea. Data on MC of pea and components during storage are shown in Figures 5.3 to 5.7. Typically, the MC increased from an initial value of 10.35% for whole sound pea to anywhere from 10.8% w.b. for test chamber 40C1 (40°C, 60% RH) to 23.2% w.b. for test chamber 10C8 (10°C, 90% RH). MC for feed-grade pea increased from an initial value of 9.6% to anywhere from 10.7% w.b. for test chamber 40F2 (40°C, 60% RH) to 22.4% for test chamber 10F8 (10°C, 90% RH). Pea adsorbed more moisture from the humid environment at low temperature as compared to the same humid environment at high temperature (Figures 5.8 and 5.9). This could be explained by the fact that EMC at a given RH decreases with increase in temperature (Stroshine, 1998). Moisture adsorption increased as RH increased from 60% to 90%. To compare the result of this experiment with water adsorption of tobacco seeds (Menkov et al., 2002) it can be said that moisture adsorption in pea and tobacco followed the expected reverse sigmoidal pattern as other agricultural products.

The exponential model (equation 4.2) was fitted to the moisture adsorption data. Parameters k and M_e were estimated using the non-linear estimation procedure (NLIN) in SAS package. The parameter estimates as well as the coefficient of multiple determination (R^2) and standard error of estimate are listed in Tables 5.4 and 5.5.

Then the Solver in Microsoft Excel was used to find the relationship of k and M_e with the RH and temperature of the experimental ambient. M_e could best be expressed as a function of RH and temperature by Henderson equation (Bala, 1997). The results are as follow. For feed-grade pea,

$$M_e = \frac{1}{100}\left[\frac{\ln(1-RH)}{-0.02\,(T+102.6)}\right]^{\frac{1}{0.02}} \tag{5.3}$$

with R^2 of 0.95 and MSE of 2×10^{-4}.

where:

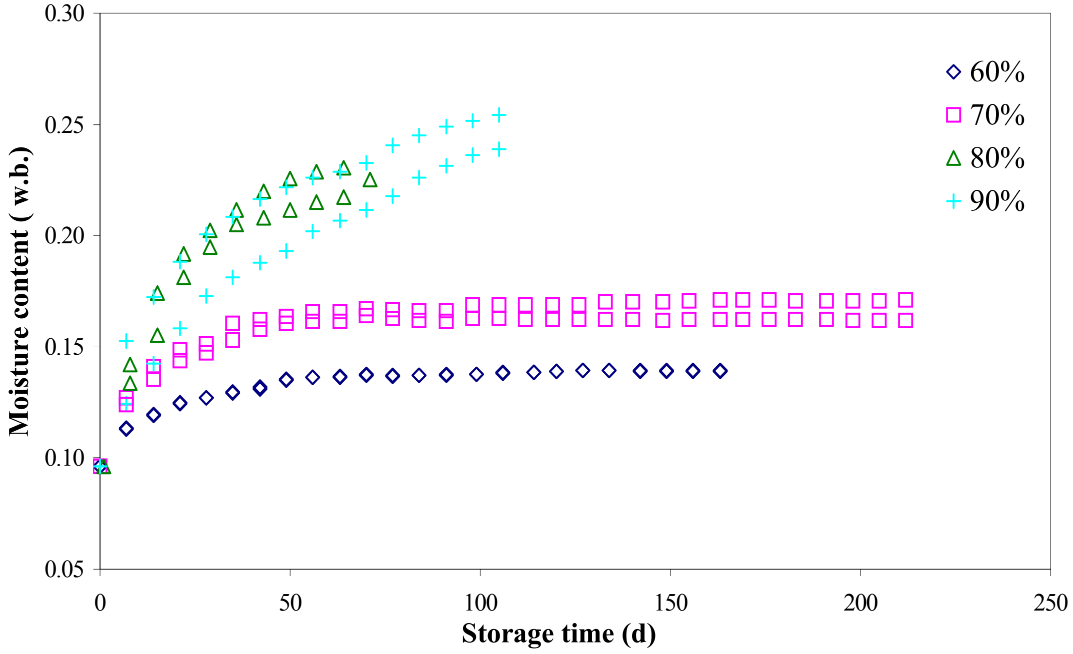
Me = equilibrium moisture content (decimal d.b.)

T = temperature (°C)

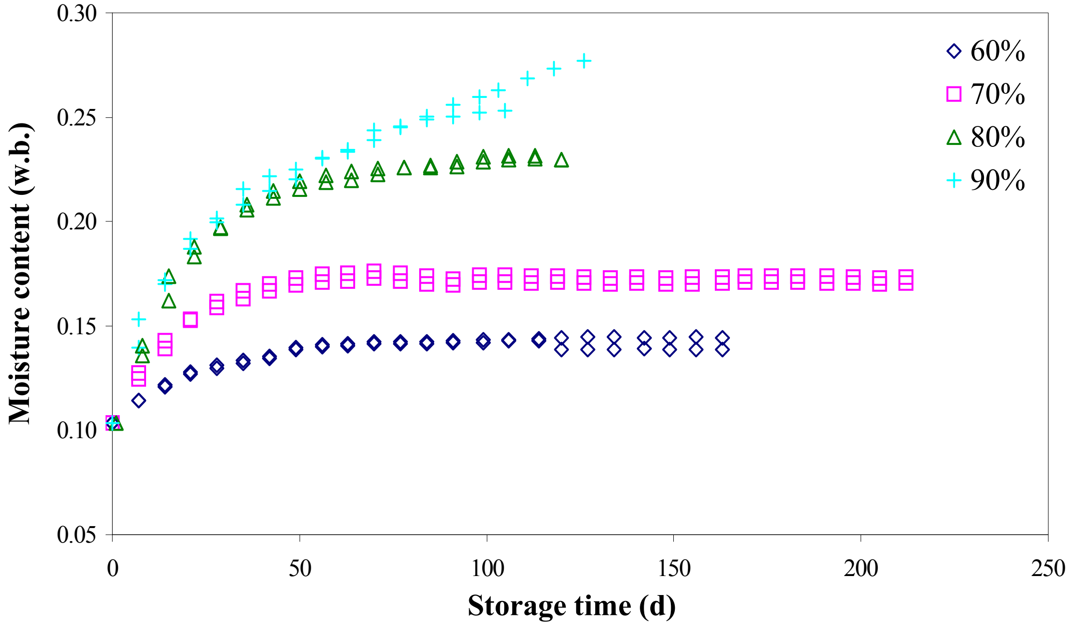
RH = relative humidity (decimal)

Table 5.3 Initial moisture content of pea and components.

Pea components	Mean moisture content (% w.b.)	Standard deviation	Number of samples
Whole yellow pea	10.35	0.06	2
Feed-grade pea	9.60	0.00	2
Shriveled yellow pea	9.76	0.04	2
Shriveled green pea	9.47	0.14	2
Cracked seed coat, yellow	9.43	0.04	2
Cracked seed coat, green	7.88	0.06	2
Split yellow pea	8.88	0.04	2
Split green pea	7.38	0.33	2
Small yellow pea	9.70	0.14	2
Small green pea	9.64	0.08	2
Whole green pea	9.60	0.00	2
Other damaged, (yellow and green)	8.55	0.03	2
Foreign material	7.60	0.07	2

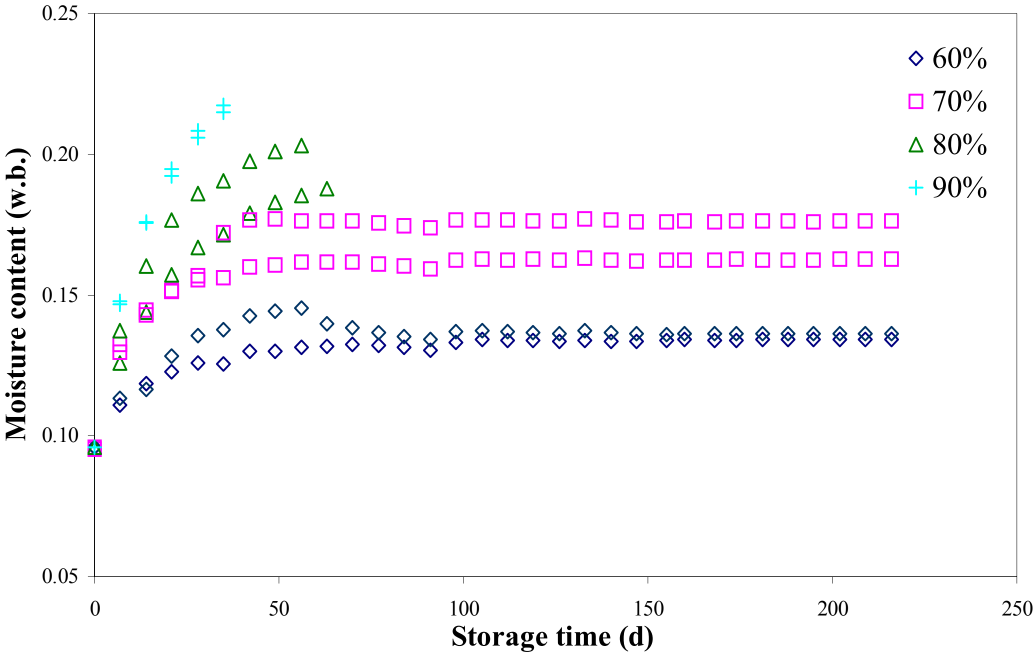


a) Feed pea

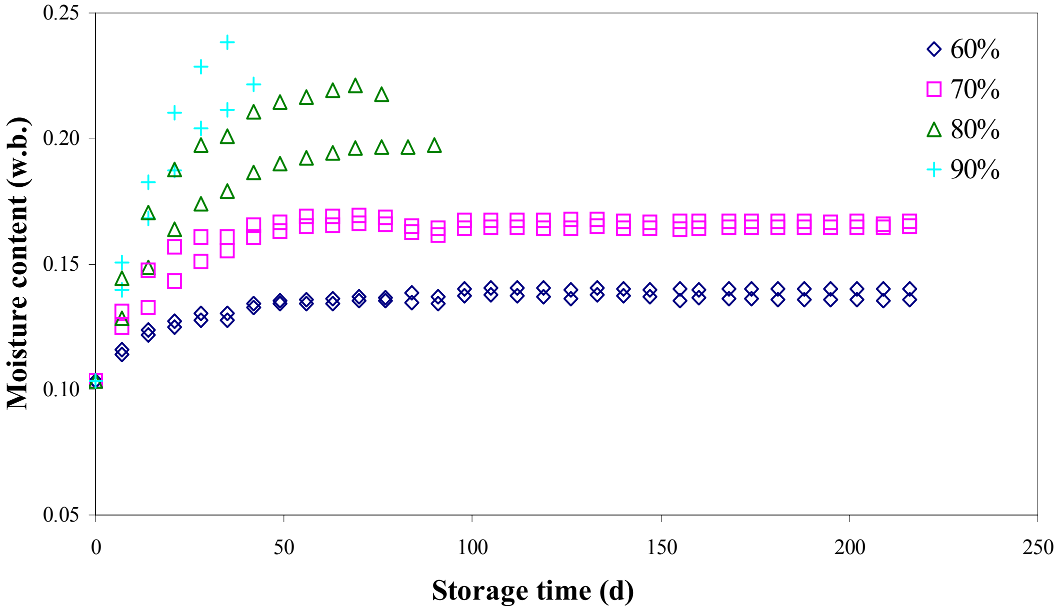


b) Clean pea

Figure 5.3 Moisture content of feed-grade and clean peas during storage at 10°C and RH of 60, 70, 80 and 90%.

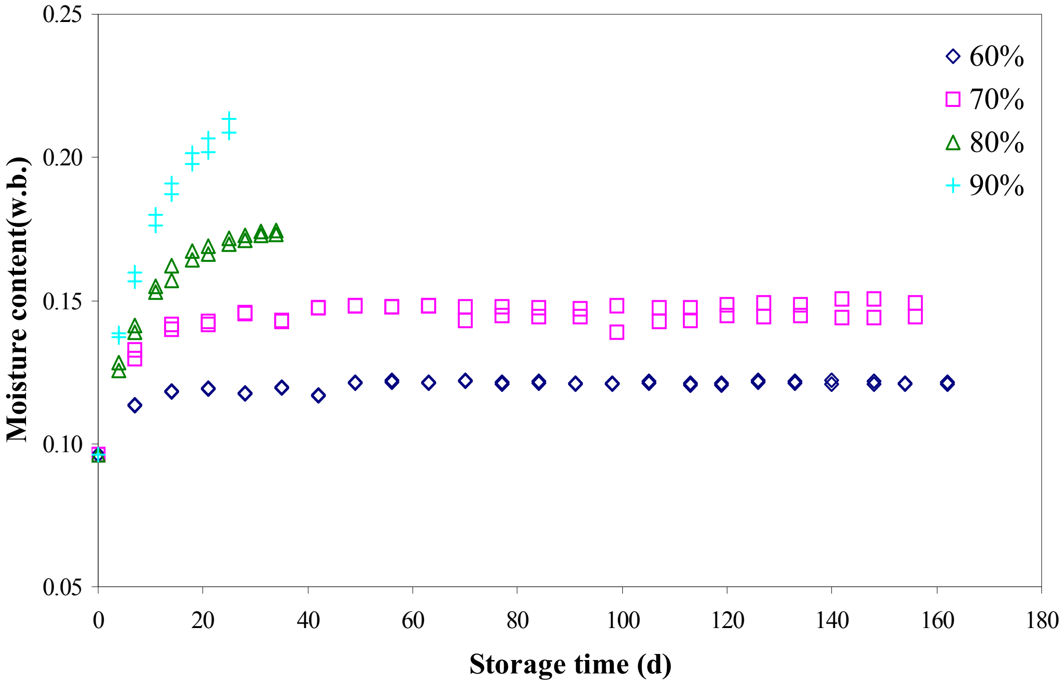


a) Feed pea

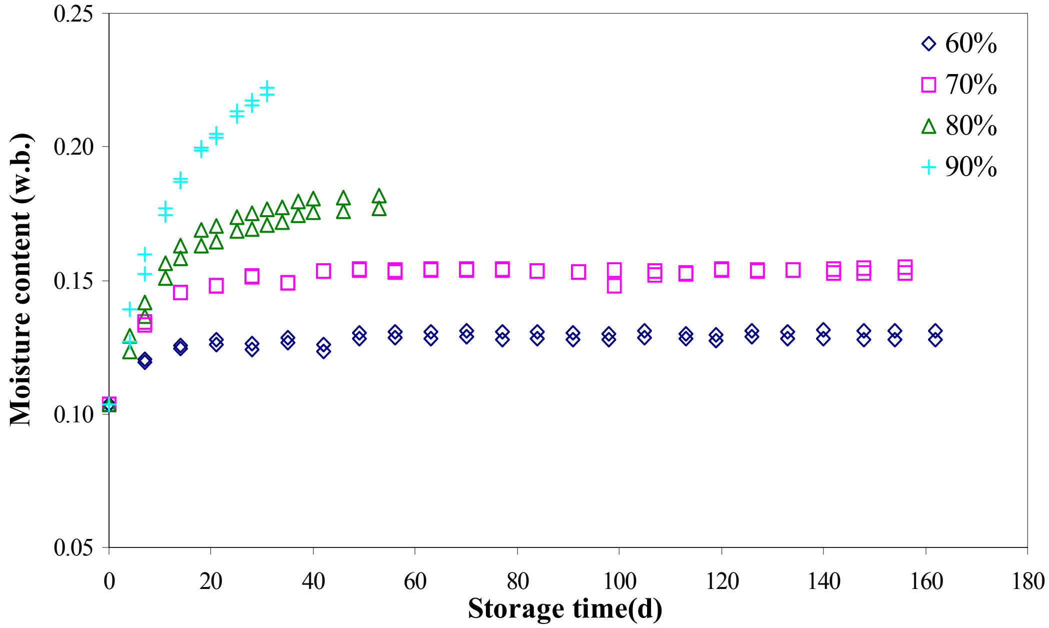


c) Clean pea

Figure 5.4 Moisture content of feed-grade and clean peas during storage at 20°C and RH of 60, 70, 80 and 90%.

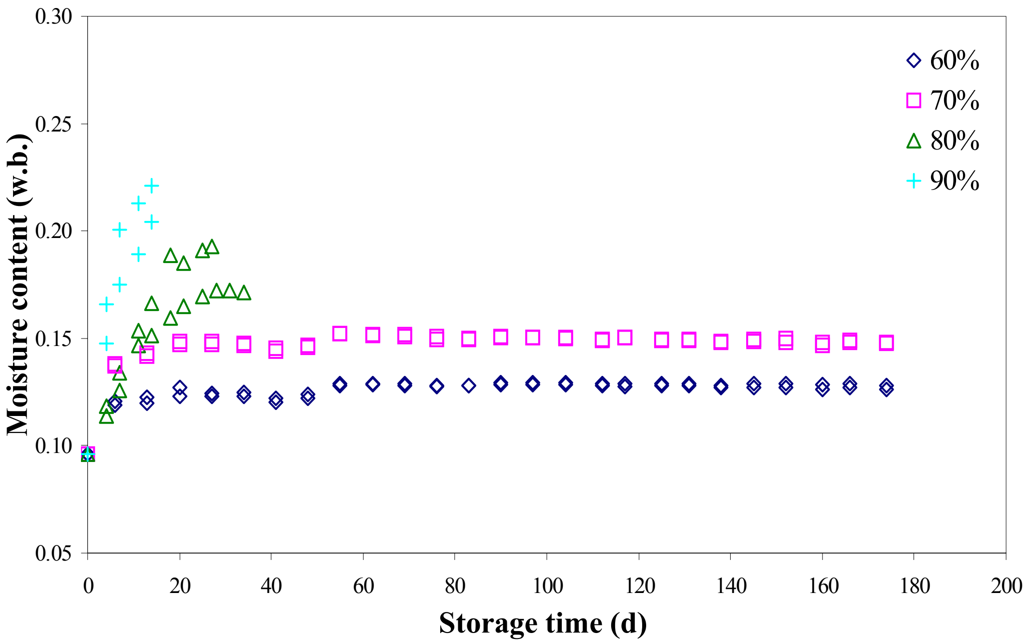


a) Feed pea

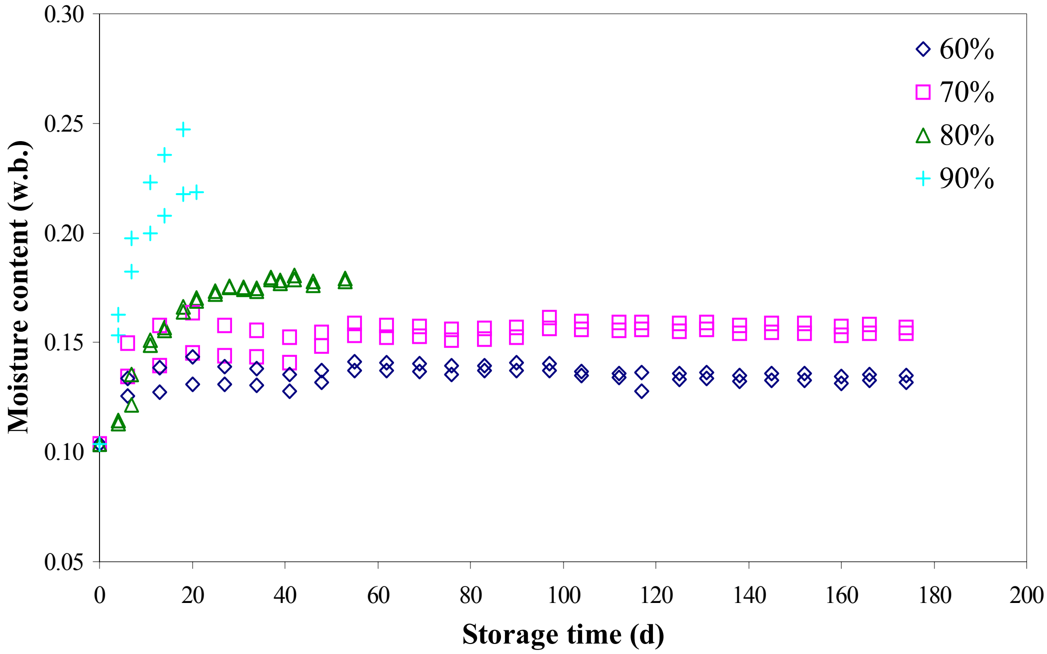


b) Clean pea

Figure 5.5 Moisture content of feed-grade and clean peas during storage at 30°C and RH of 60, 70, 80 and 90%.



a) Feed pea



b) Clean pea

Figure 5.6 Moisture content of feed-grade and clean peas during storage at 40°C and RH of 60, 70, 80 and 90%.

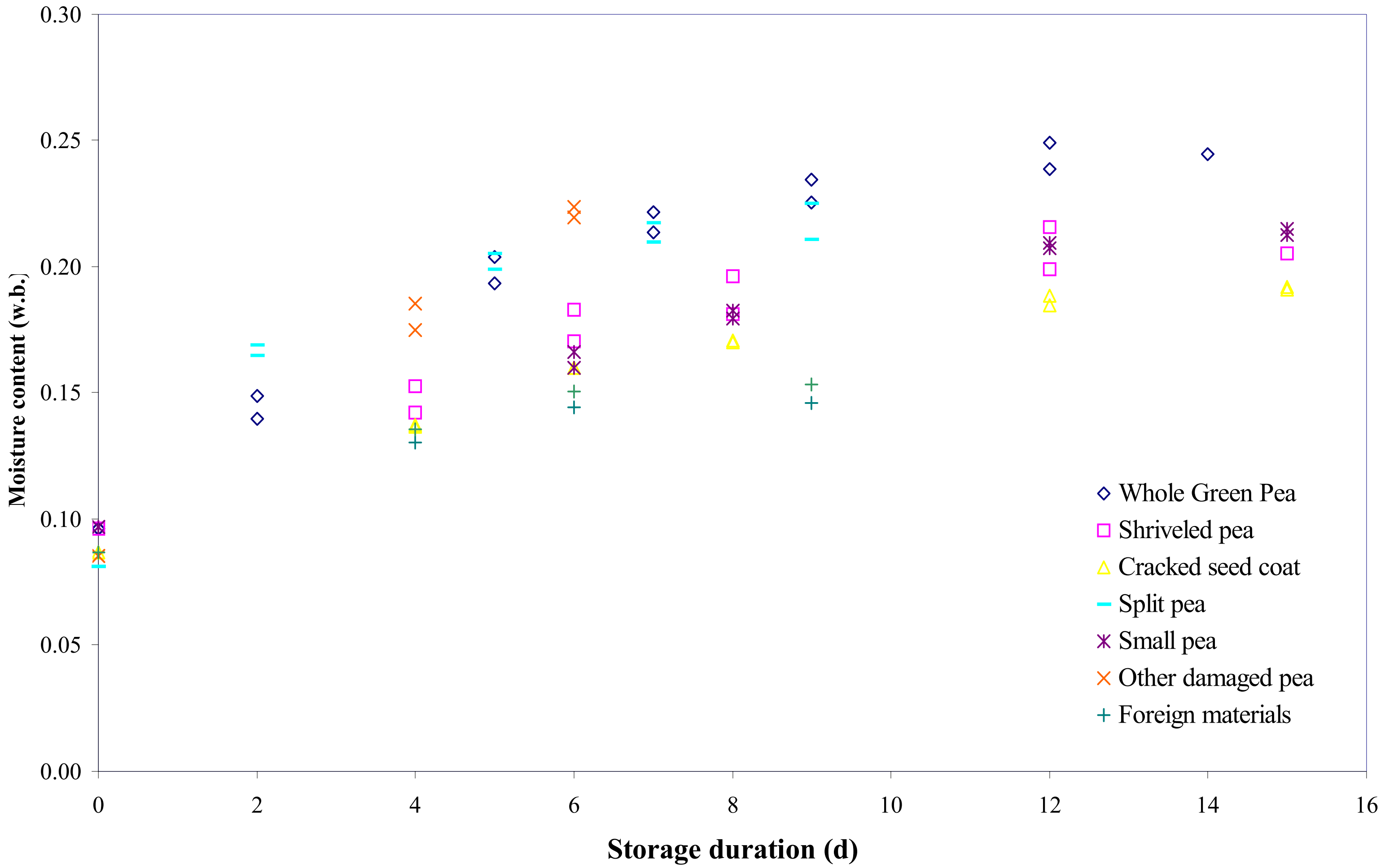


Figure 5.7 Moisture content of feed pea components during storage at 40°C and 90% RH.

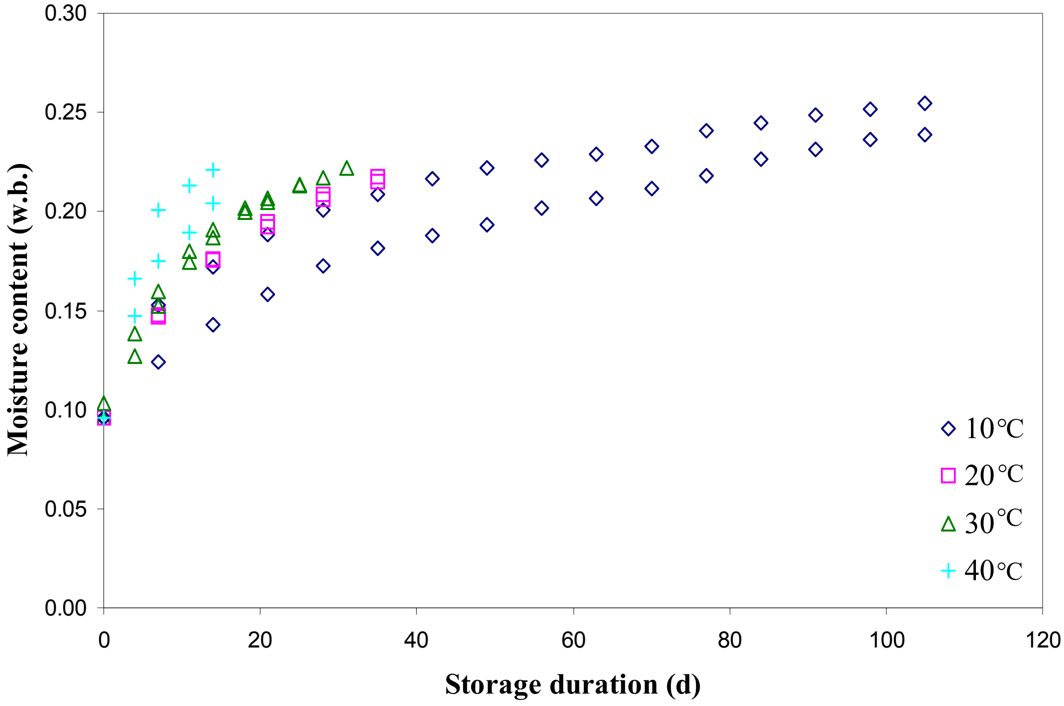


Figure 5.8 Moisture content of feed-grade pea during storage at temperatures of 10, 20, 30 and 40°C and RH of 90%.

$$k = -19.2 + 80.8\ RH + 0.02\ T - 0.02\ RH\ T - 112.6\ RH^2 + 51.9\ RH^3 \tag{5.4}$$

with R^2 value of 0.80, MSE of 7.1×10^{-4} and a random residual distribution with both RH and temperature (Appendix D).

where:

k= exponential constant (min^{-1})

For whole sound pea,

$$M_e = \frac{1}{100}\left[\frac{\ln(1-RH)}{-0.02\,(T+135.3)}\right]^{\frac{1}{0.02}} \tag{5.5}$$

with R^2 value of 0.93 and MSE of 3.5×10^{-4}.

$$k = -29.4 + 124.5\ RH + 0.02\ T - 0.03\ RH\ T - 174.9\ RH^2 + 81.5\ RH^3 \tag{5.6}$$

with R^2 value of 0.91 and MSE of 4×10^{-4} and a random residual distribution with both RH and temperature (Appendix D).

Equations 5.5 to 5.8 show that both constants (k & M_e) are functions of temperature and RH of the storage. But RH has a larger impact on k value than temperature of the storage. Equations 5.5 to 5.8 should be used with caution and only within the tested ranges of temperature (10° to 40°C) and RH (60 to 90%).

Table 5.4 Values of k and M_e in equation 4.2 obtained by NLIN regression analysis for feed pea.

Temperature (°C)	RH (%)	k (min^{-1})	M_e (% d.b.)	R^2	Standard error of estimate
10	60.7	0.0498	16.1	0.98	0.0015
	70.2	0.0584	19.9	0.94	0.0051
	79.2	0.0474	29.9	0.98	0.0094
	80.6	0.0268	33.1	0.90	0.0205
20	59.5	0.0684	15.6	0.86	0.0044
	71.6	0.0716	20.4	0.81	0.0098
	74.8	0.0547	24.4	0.92	0.0013
	82.0	0.0572	30.1	0.99	0.0022
30	58.0	0.1584	13.7	0.95	0.0016
	70.4	0.1590	17.1	0.95	0.0033
	76.8	0.1115	21.3	0.99	0.002
	83.6	0.0687	30.1	0.99	0.0033
40	60.7	0.1824	14.6	0.87	0.003
	71.5	0.2224	17.5	0.96	0.0026
	76.9	0.0738	23.5	0.88	0.0146
	86.4	0.1474	29.3	0.94	0.0168

Table 5.5 Values of k and M_e in equation 4.2 obtained by NLIN regression analysis for clean pea.

Temperature (°C)	RH (%)	k (min^{-1})	M_e (% d.b.)	R^2	Standard error of estimate
10	60.2	0.0426	16.6	0.97	0.0025
	70.9	0.0587	20.9	0.98	0.0029
	80.8	0.0440	29.9	0.99	0.0035
	82.5	0.0260	36.6	0.98	0.0107
20	58.3	0.0469	16.0	0.94	0.0027
	71.1	0.0640	19.9	0.96	0.0039
	78.0	0.0523	26.2	0.87	0.0176
	82.0	0.0450	33.1	0.94	0.0169
30	58.0	0.1277	14.8	0.91	0.0023
	70.2	0.1227	18.1	0.98	0.0019
	77.6	0.0890	21.8	0.98	0.0042
	83.0	0.0617	31.2	0.99	0.0039
40	61.7	0.2669	15.6	0.74	0.0048
	70.9	0.2035	18.3	0.79	0.0069
	77.4	0.0619	22.6	0.97	0.0062
	84.6	0.1273	31.5	0.92	0.0194

Moisture adsorption of pea was faster inside the dynamic environment, where air was circulated by a fan inside the chamber, than the static environment, which explains the important role of air velocity inside the storage. Air circulation inside the storage make moisture penetration inside the pea faster, as a result MC of the pea inside the dynamic storage equilibrate with RH of air more quickly than those inside the static storage. The value of M_e obtained from the moisture adsorption experiment inside the dynamic environment was much lower than those estimated from moisture adsorption data inside the static environment. Also, the estimated value of parameter k is higher in the static environment than the dynamic environment at the same condition of temperature and RH.

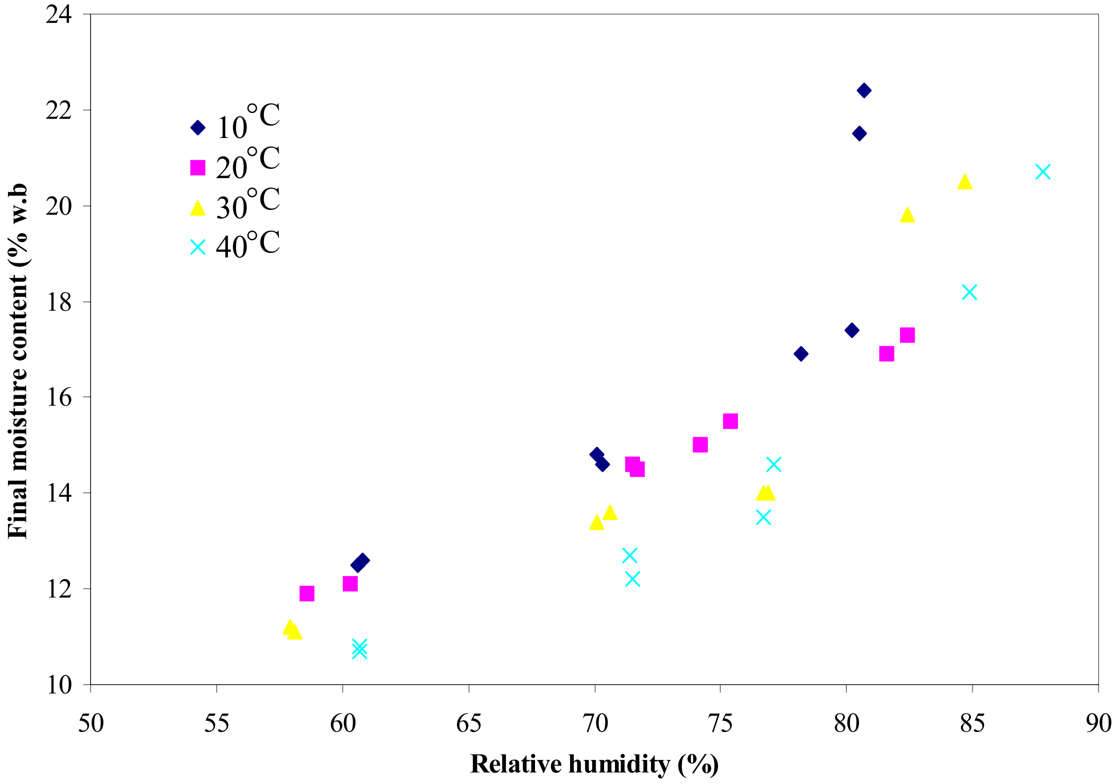


Figure 5.9 Final moisture content of feed-grade pea for given storage temperature and relative humidity.

5.3 Fungi Identification

The detailed results of fungi identification are presented in Appendix C (R. Morrall, Professor Emeritus, Dept. of Biology, University of Saskatchewan). The majority of fungi isolated were species of *Aspergillus* and *Penicillium*. Fungi were not identified to species level in this experiment because it was a highly specialized and time-consuming task. The classification scheme used for the *Aspergillus* and *Penicillium* spp. in this work was based on microscopic and cultural characteristics; upon this classification, they were numbered into putative (mentioned or believed as a formal category) species. In some cases, it was not even possible to classify *Aspergillus* and *Penicillium* into putative species because the growth of fast-growing fungi, such as *Rhizopus* and *Mucor*, in the petri dishes had interfered so much with the growth of the former fungi. These cases were reported as, for example, *Aspergillus* #? (refer to Appendix C). The single species of *Rhizopus, Mucor* and *Cladosporium* found were also not identified to species because of the lack of sporulation. The three fungi that were identified to species level are either common saprophytes on dead plant tissues (*Alternaria alternata, Fusarium equiseti*) or a known foliar pathogen of pea (*Ascochyta pinodes*).

Aspergillus, *Penicillium*, *Rhizopus, Mucor* and *Nigrospora* are mainly storage fungi, whereas, *Alternaria alternata, Fusarium equiseti, Cladosporium* sp. *and Ascochyta pinodes* are field fungi. Field fungi may cause molding of plant products in storage, but they invade the seeds while the plants are still growing in the field. All of field fungi have high water requirements for growth. The damage caused by field fungi is done before harvest and does not continue to increase during storage. With a few exceptions, storage fungi develop only after the product is in the storage. Storage fungi are common in materials exposed constantly to RH of 65-90%, where free water is not available (Sauer, 1992).

Seeds that had been stored at higher temperatures and RH levels were molded mainly by storage fungi. This is evident not only because of the predominance of *Aspergillus* and *Penicillium* among the fungal isolates, but also because seeds that were surface sterilized before isolation produced fewer fungal colonies that grew less during incubation, or sometimes no fungi grow at all. This suggests that, at the time the seeds were removed from storage for testing, the storage fungi had only just started growing on the seed coats and had not penetrated enough to be protected from the surface sterilant. Field fungi that had already penetrated deep in the seed coat would be protected from the surface sterilant and would still have grown out of the seed on the agar during incubation. Sometimes, the recovery of *Alternaria* from surface disinfected seeds is evidence of good storage, because it shows that seeds are about the same condition as they were harvested. Decrease in percentage of seeds yielding *Alternaria* and increase in percentage yielding species of the *Aspergillus* is an early alert of potential storage condition problems. Figures 5.10 to 5.12 show a close up view at the fungi that appeared on both clean and feed pea.

Figure 5.10 Photograph of the *Aspergillus* appeared on clean pea at 40°C and 90% RH.

Table 5.6 summarizes the observed fungi at each temperature and RH. Only species of *Aspergillus* and *Penicillium* that are storage fungi were identified on clean pea and no field fungi was observed on clean pea at all the temperatures tested.

Figure 5.11 Photograph of the fungi appeared on feed pea at 40°C and 90% RH.

Figure 5.12 Photograph of the fungi that appeared on feed pea at 10°C and 90% RH.

Many storage fungi are thermophilic or thermotolerant and can contribute to heating in storage. Whether this applies to any of the *Aspergillus* and *Penicillium* spp. in this investigation was not determined because the isolations were made at room temperature. However, there were some *Aspergillus* types that were commonly found on seeds stored at all temperatures and RH, and others that were found in only a few cases. This difference may be related to temperature, but one cannot rule out the effect of seed lot origins.

Table 5.6 Type of molds observed on both feed pea and clean pea after spoilage**.**

Temperature (°C)	RH (%)	Type of pea	Mold species
10	80	Clean	*Aspergillus*
10	80	Feed	*Aspergillus, Penicillium, Alternaria alternata*
20	80	Clean	*Aspergillus*
20	80	Feed	*Aspergillus, Penicillium,* Bacterium *Cladosporium, Alternaria alternata, Ascochyta pinodes,* unknown fungus
20	90	Clean	*Aspergillus, Penicillium*
20	90	Feed	*Aspergillus, Penicillium, Rhizopus, Alternaria alternata, Mucor Fusarium equiseti,* unknown fungus
30	80	Feed	*Aspergillus, Penicillium, Rhizopus Alternaria alternata*
30	80	Clean	*Aspergillus, Penicillium*
30	90	Feed	*Aspergillus, Penicillium, Rhizopus Alternaria alternata, Mucor*
30	90	Clean	*Aspergillus, Penicillium*
40	80	Clean	*Aspergillus*
40	80	Feed	*Aspergillus,* Bacterium
40	90	Clean	*Aspergillus*
40	90	Feed	*Aspergillus, Penicillium, Rhizopus*

Mycotoxin contamination of foods and feeds affects the marketing and utilization of grains, because they may contribute to human and animal health problems. Mycotoxins are fungal metabolites that are toxic to animals. The important toxigenic species of *Aspergillus* are *A. chevalieri, A. clavatus, A. flavus, A. fumigatus, A. niger, A. ochraceus, A. parasiticus and A. versicolar.* The important toxigenic species of *Penicillium are P. citinum, P. verrucosum var. cyclopium, P. islandicum, P. purpurogenum, P. roquefortii,* and *P. verrucosum var. verrucosum* (Sauer, 1992).

Aspergillus spp. may play a role in clinical settings such as opportunistic infections, allergic states and toxicoses in human. These fungi can cause infections in animals as well as in man. In birds, respiratory infections may develop due to *Aspergillus*. It may induce mycotic abortion in cattle and sheep. Ingestion of high amounts of aflatoxin may induce lethal effects in poultry animals fed with grain contaminated with the toxin (Anonymous, 2005b)

Limited work was available to be compared with the current study on mold identification task of stored pea. The important storage fungi reported by Mills and Woods (1994) on whole sound pea (*Pisum sativum L.* 'Titan') were species of *Penicillium* and *Eurotium*, *Rhizopus arrhizus* Fisher, *Aspergillus flavus* Link, *A. candidus* Link and to a lesser extent *A. ochraceus* Wilhelm and *A. wentii* Wehmer. The preharvest fungi identified in their study were *Cladosporium cladosporioides* and *Alternaria alternata* and bacteria. As in this study, only storage fungi, *Aspergillus* and *Penicillium* spp., were identified on whole sound pea.

Fungi were not identified to species level in this experiment, one cannot rule for sure if they are toxic to animals or not, but as the comparison with literature shows they probably are toxic.

5.4 Mold-free Days

The number of days based on visual inspection the pea samples surface was mold-free, MC of pea at the end of storage or at the time of mold appearance, RH and RH standard deviation are listed in Tables 5.7 to 5.9. Mold growth occurred above 16.2% MC for feed pea components (small pea at 40°C, 90% RH). Mold appeared on feed-grade pea above 13.5% MC at high temperature (40°C, 80% RH) and MC above 15% at lower storage temperature (20°C, 80% RH). For clean pea, mold appeared above 14% MC at high temperature (40°C, 80% RH) and above 14.8% at lower storage temperature (20°C, 80% RH). As fungi like elevated temperature and RH, shorter mold-free days of storage were resulted from storage at higher temperature and higher RH. Mold was not detected visually on both feed-grade and clean peas at temperatures of 10, 20, 30 and 40°C and RH of 60 and 70% for the whole experiment duration, 216 days at 10 and 20°C, 162 and 156 days at 30°C and RH of 60 and 70% respectively; and, 174 days at 40°C. Due to the problem with RH and changing the salt solution the number of mold-free days for pea at 10°C and 60% was 163 days, we could speculate that storage duration at this condition would also be 216 days or longer. Sample photographs of peas' surface condition at the end of the test are shown in Figures 5.13 to 5.15. More photographs can be found in Appendix E.

As the preliminary testing on feed pea components at 40°C and 90% RH shows, other damaged pea was the first component that was molded after 6 days of storage followed by foreign material and split pea that both molded after 9 days of storage. The same result was concluded from daily visual observation. Other damaged pea or the foreign materials were the first components that became moldy inside the petri dishes at any storage condition.

To compare the results of the current study with the work done by Booth et al. (2001) and Empringham et al. (2002) on the number of mold-free days for both feed and clean peas, it could be said that the number of mold-free days reported by Booth et al. (2001) was much lower than what was obtained in this experiment. Although Empringham et al. (2002) results were more similar to this work, but there is no consistency in the number of mold-free days in their study, i.e., there was 109 mold-free days at 40°C and 81.7% RH, whereas, there was only 35 mold-free days at 30°C and 82.9% RH in their experiment which was not explained.

Table 5.7 Relative humidity and number of mold-free days for feed pea components.

Feed pea Components	Relative humidity (%)		Mold-free days	MC at mold onset (% w.b.)
	Mean	Standard dev.		
Other color	86.4	5.70	12	21.0
	85.6	5.40	14	20.2
Shriveled	90.0	3.39	12	20.5
	87.9	4.59	15	19.6
Cracked seed coat	88.2	2.96	15	19.6
	87.9	3.82	15	19.4
Split	85.4	5.70	9	20.1
	86.4	4.70	9	21.2
Small	84.9	2.70	15	16.2
	85.9	4.56	15	16.3
Other damage	88.5	1.34	6	21.7
	87.5	1.27	6	22.0
Foreign material	85.7	5.47	9	18.1
	88.0	5.52	9	18.9

Table 5.8 Relative humidity of storage chambers and number of mold-free days for whole sound pea.

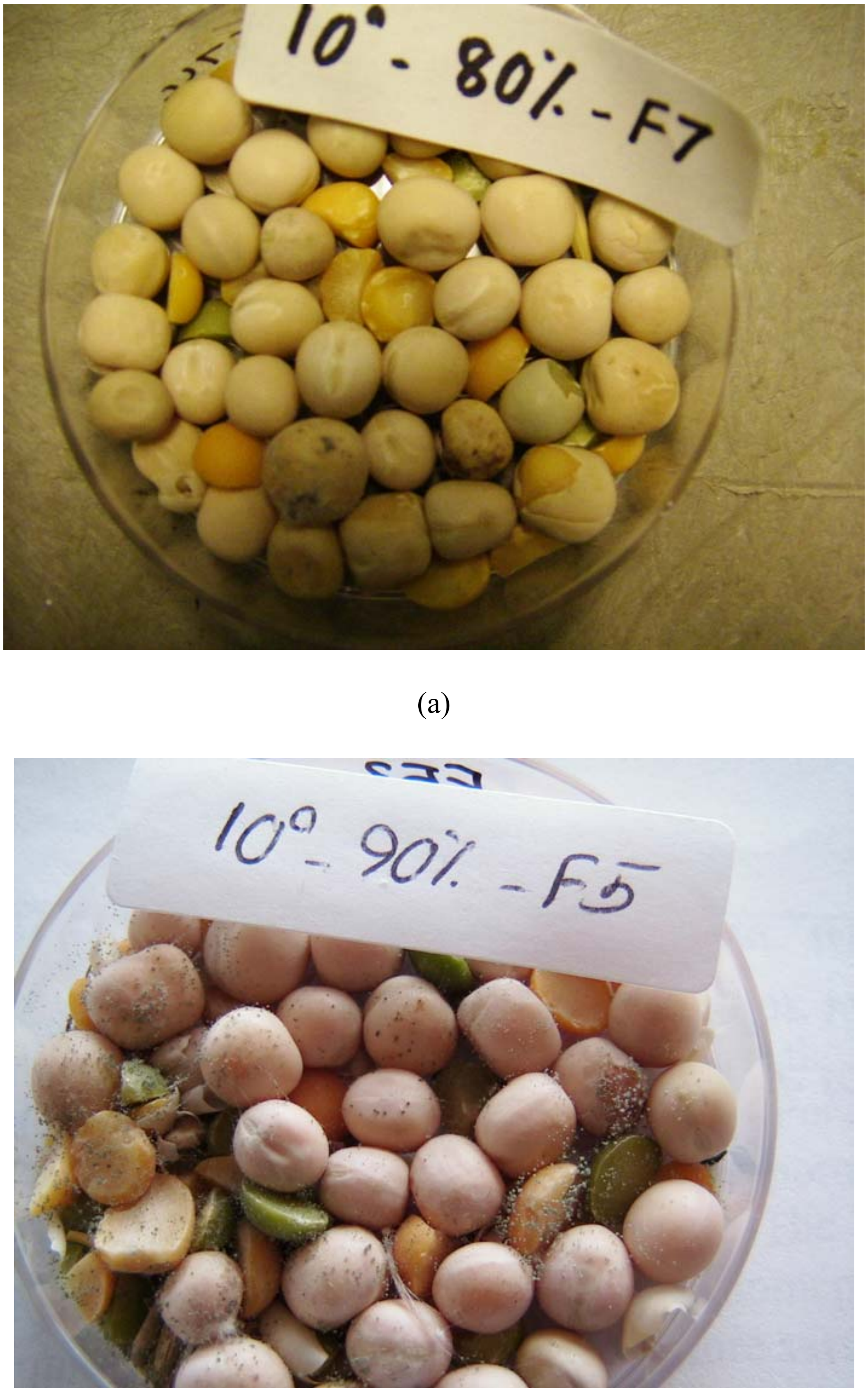
Temperature (°C)	Relative humidity (%)		Mold-free days	MC at mold onset (% w.b.) Termination of storage
	Mean	Standard dev.		
10	60.1	1.60	163*	12.4
	60.3	1.10	163*	12.5
	71.0	2.52	212*	14.9
	70.7	3.11	212*	14.5
	80.9	3.07	119	20.3
	80.6	3.37	119	21.1
	81.0	5.09	125	20.5
	83.9	3.27	104	23.2
20	58.8	2.10	216*	11.8
	57.7	2.50	216*	11.5
	70.5	2.90	216*	14.4
	71.6	2.10	216*	14.8
	79.4	5.19	76	15.9
	76.6	4.79	90	14.8
	81.4	5.04	42	15.7
	82.5	5.39	35	17.4
30	57.9	1.00	162*	11.1
	58.0	1.90	162*	11.0
	70.3	2.60	156*	13.4
	70.1	2.20	156*	13.3
	77.7	2.57	53	14.6
	77.2	3.02	53	14.5
	83.1	4.04	31	20.8
	82.8	4.34	31	20.9
40	62.4	2.90	174*	10.8
	61.0	0.80	174*	10.8
	69.7	1.80	174*	12.5
	72.1	1.60	174*	12.8
	77.5	4.30	53	14.1
	77.2	4.36	53	14.0
	86.3	5.30	18	21.4
	82.9	5.83	21	16.5

* Samples were not molded at this time.

Table 5.9 Relative humidity of storage chambers and number of mold-free days for feed-grade pea.

Temperature (°C)	Relative humidity (%)		Mold-free days	MC at mold onset (% w.b.) termination of storage
	Mean	Standard dev.		
10	60.6	1.30	163*	12.5
	60.8	1.20	163*	12.6
	70.3	2.86	213*	14.6
	70.1	2.77	213*	14.8
	78.2	5.34	64	16.9
	80.2	3.81	71	17.4
	80.5	4.98	105	21.5
	80.7	5.07	105	22.4
20	58.6	2.20	216*	11.9
	60.3	2.70	216*	12.1
	71.7	2.90	216*	14.5
	71.5	2.10	216*	14.6
	75.4	8.92	56	15.5
	74.2	5.02	63	15.0
	81.6	5.66	35	16.9
	82.4	6.16	35	17.3
30	57.9	2.20	162*	11.2
	58.1	2.10	162*	11.1
	70.6	2.10	156*	13.6
	70.1	2.50	156*	13.4
	76.9	3.22	34	14.0
	76.7	3.27	34	14.0
	84.7	3.57	25	20.5
	82.4	3.83	25	19.8
40	60.7	0.80	174*	10.8
	60.7	2.40	174*	10.7
	71.5	0.50	174*	12.2
	71.4	0.80	174*	12.7
	76.7	4.26	34	13.5
	77.1	7.38	27	14.6
	84.9	3.45	14	18.2
	87.8	0.60	14	20.7

- Samples were not molded at this time.



(a)

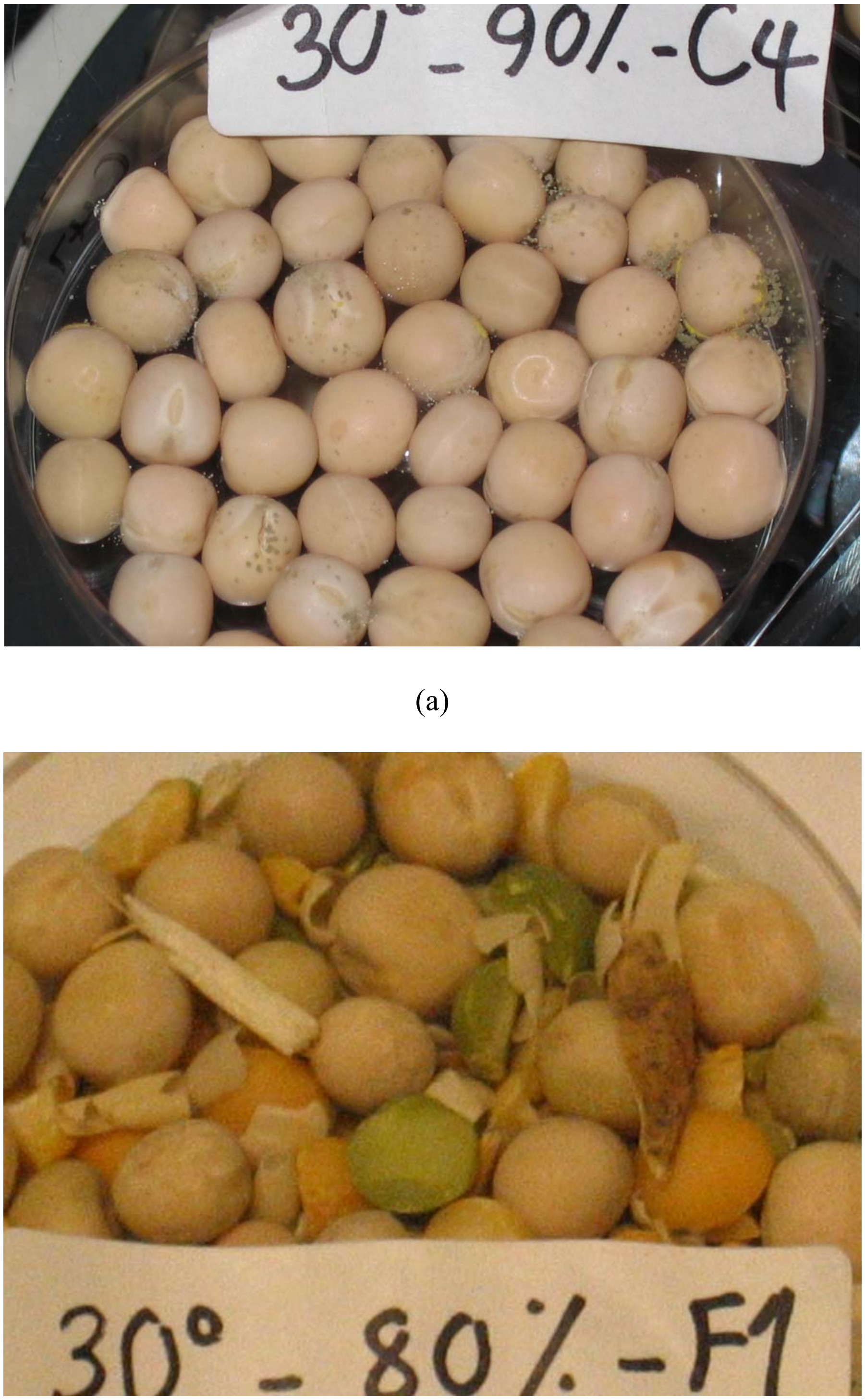
(b)

Figure 5.13 Feed pea surface condition after 64 days of storage at 10°C and 78.2% RH (a); and after 105 days at 10°C and 80.5% RH (b).

(a)

(b)

Figure 5.14 Clean pea and feed pea surface condition at 20°C and 80% RH after 76 (a) and 56 (b) days of storage, respectively.



(a)

(b)

Figure 5.15 Clean pea and feed pea appearance at termination of storage at 30°C and 90 and 80% RH for 31(a) and 34 (b) days respectively.

Equation 4.12 was fitted to the number of mold-free days (d) as a function of temperature and RH for both feed and clean peas. For clean pea,

$$Y = e^{(12.35 - 0.055\,T - 8.69\,RH)} \quad (5.9)$$

with R^2 of 0.91 and MSE of 140.73.

For feed-grade pea,

$$Y = e^{(7.10 - 0.05\,T - 2.71\,RH)} \quad (5.10)$$

with R^2 of 0.81 and MSE of 163.67.

Equations 5.9 and 5.10 are valid for temperature range of 10 to 40°C and RH range of 80 to 90% up to 105 days of storage for feed-grade pea and up to 126 days of storage for clean pea. A similar equation was used by Khoshtaghaza et al. (1999) for alfalfa cubes during transit and storage. The number of mold-free days obtained by equation 5.10 for clean pea was compared to the number of mold-free days for alfalfa cube in similar condition of temperature and RH. Clean pea had a higher number of mold-free days in identical storage condition. This could be explained by the fact that alfalfa cube is a porous product, composed of small particles, which are compressed to form a cube, whereas clean pea is a seed with a seed coat and has less capacity to adsorb moisture.

The spoilage index (SI) was calculated similar to the SI indicated by Khoshtaghaza et al. (1999), using equation 4.13. However, this equation could simply be expressed as:

$$SI = \frac{Y_{exp}}{Y_{Cal}} \quad (5.11)$$

where:

Y_{exp} = experimental storage time at which the samples went molded (d)

Y_{cal} = calculated storage time from equation 5.9 (d)

The values for spoilage index for both feed and clean pea are presented in Tables 5.10 and 5.11 respectively. SI is indicative of pea quality during transport and storage. Good quality pea has a low SI and spoiled and molded pea has SI ≥ 1.

Table 5.10 Spoilage index values for clean pea.

Temperature (°C)	Mean RH (%)	Storage duration (d)	Spoilage index
10	80.9%	120	1.01
10	80.6%	120	0.99
10	81.0%	126	1.07
10	83.9%	105	1.15
20	79.4%	79	1.01
20	76.6%	93	0.94
20	81.4%	43	0.66
20	82.5%	36	0.61
30	77.7%	54	1.04
30	77.2%	54	0.99
30	83.1%	32	0.98
30	82.8%	32	0.96
40	77.5%	40	1.31
40	77.2%	54	1.72
40	86.3%	19	1.34
40	82.9%	22	1.15

As Tables 5.10 and 5.11 show, when SI ≥ 1 the probability of pea to go molded is 100%. For example, the probability of clean pea to go molded after 43 d of storage at 20°C and 81.4% RH is only 0.66, whereas clean pea will surely go molded after 79 days of storage at 20°C and 79.4% RH. These values are only correct for temperatures of 10, 20, 30 and 40°C and RH of 80 and 90%. There are a number of uncertainties in these calculations. It was expected for all the spoiled and moldy samples to have a SI ≥ 1, whereas in some cases in this study when mold appeared on the samples, SI was lower than one. RH and temperature should be taken every hour for SI to be more accurate. Tables 5.10 and 5.11 demonstrate how the mold-free days equation (equations 5.9 and 5.10) can be used to determine the SI of a batch of stored pea as long as the storage condition (temperature and RH) are monitored, e.g. every 1 h.

Table 5.11 Spoilage index values for feed-grade pea.

Temperature (°C)	Mean RH (%)	Storage duration (d)	Spoilage index
10	80.5	105	1.28
10	80.7	105	1.28
10	78.2	64	0.73
10	80.2	71	0.86
20	81.6	35	0.73
20	82.4	35	0.74
20	75.4	56	0.98
20	74.2	63	1.07
30	84.7	25	0.94
30	82.4	25	0.88
30	76.9	34	1.03
30	76.7	34	1.03
40	84.9	14	0.88
40	87.8	14	0.95
40	76.7	34	1.71
40	77.1	27	1.37

The SI indicated by Khoshtaghaza et al. (1999), which is for alfalfa cube during transit from Canada to Taiwan showed a value equal or higher than one in all the cases that samples became moldy. The reason is that they collected the data (RH and temperature of storage) every hour, so they had more reliable data and spoilage index that was calculated was more accurate.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study focused on the effect of adverse storage conditions on the moisture adsorption and spoilage characteristics of pea. Samples of Pea were exposed to temperatures of 10 to 40°C and RH of 60 to 90%. The data obtained from both feed pea, whole sound pea and feed pea components during storage showed that pea adsorbed moisture and in conditions of high temperature and high RH they became moldy.

The following conclusions can be drawn:

1) The storage stability of pea is similar to other agricultural products; they can be kept safe at low temperature and low humidity. Particularly, this research showed that maintaining temperatures and RH in the airtight chambers below 20°C and 70% extended the storage life of both clean and feed pea to more than 216 days (maximum number of days tested at these conditions). Maintaining temperature and RH below 40°C and 70% extended the shelf life of both feed pea and clean pea to more than 174 days (maximum number of days tested at these conditions). Therefore, during transport and storage, temperature and RH should not exceed the mentioned values for both whole sound pea and feed-grade pea, i.e., if the temperature exceeds 30°C and RH exceeds 85% during transport and storage feed pea will go molded in 25 days.
2) At the same condition of temperature and RH, it took longer for clean pea to become moldy as compared to feed-grade pea. The presence of foreign materials in feed pea explains the fact that these components adsorb more moisture. Thus, foreign materials increase the susceptibility of feed pea to microbial development

and quality deterioration. Apart from accumulating adsorbed moisture, foreign materials may also block natural airflow in storage, thus, creating an environment conducive to localized mold development and subsequent heating (hot spots). Foreign materials are also carrier of storage and field fungi and bacteria. Beside foreign materials, presence of other damaged and split pea also accelerate the rate of molding.

3) Equations were fitted to the data to describe the moisture adsorption of pea during storage under tropical conditions in both dynamic and static storage conditions. Among these equations, the exponential model was chosen to fit the moisture adsorption of pea. The constant k in this model depends on variables such as temperature and RH of the storage environment.
4) The concentration of CO_2 was measured inside the chambers during storage. The results showed that the condition inside the airtight chambers during storage was not anaerobic. The increase in CO_2 concentration during storage was within the range of normal CO_2 content in the air until molds appeared on the samples. This was more evident at high temperature and high RH.
5) The appearance of visible mold on the pea samples is the most important factor in downgrading and rejection of pea. The critical temperatures and RH and number of days before visible mold was developed during the storage period were detected in this experiment. Based on this study, high temperatures (>20°C) and high RH (>70%) should be avoided in the storage of pea.
6) A preliminary test was done on the effect of feed pea components on molding. As a result of this experiment, other damaged pea (any discoloration or physical

damage on the face of the cotyledon), foreign materials and split pea were identified as the most putative components to molding.

7) Models were developed based on the mold-free days for both feed-grade and whole sound peas showing how many days pea can be stored mold free by knowing the temperature and RH of the storage environment. Also, a spoilage index (SI) was calculated that can be used to show the onset of mold growth during transport and storage. When the SI ≥ 1 the samples already became molded.
8) Fungi that appeared on the pea samples were identified. In whole sound pea at all temperatures and RH, only species of *Aspergillus* and *Penicillium* (storage fungi) were observed. On feed-grade pea, aside from storage fungi such as *Aspergillus* and *Penicillium spp., Rhizopus* and *Mucor spp*. were observed, field fungi such as, *Alternaria alternata, Cladosporium spp.*, *Fusarium equiseti* and *Ascochyta pinodes and* bacterium were also identified, suggesting that foreign materials in feed-grade pea pose greater risk of microbial development during adverse storage conditions.

6.2 Suggestions for Future Research

There are a few tips about this experiment that will facilitate conducting similar experiments and make the results more accurate for future research:

- A better means of controlling RH must be used than using salt solutions to avoid the dramatic variations in RH during experiment, especially at higher RH setting such as 90%.

- The experiment duration can be extended until all the samples at all temperatures and RH become molded, this way, mold-free days model could be applied for a larger domain of temperature and RH.
- Fungi could be identified to species level to find whether or not they are toxic to humans and animals.

6.3 Recommendations

The following recommendations can be drawn from this experiment to make transport and storage of pea safer:

- In order to increase the shelf life of pea during the transport or storage to more than 216 days, the storage temperature should be maintained at 20°C or less and RH at 70% or less.
- The moisture content of pea should be reduced to less than 11% in order to increase the storage life of the product.
- Other damaged pea could be removed to the least possible level and foreign materials should be reduced to less than 2% in order to increase the shelf life of feed-grade pea.

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APPENDIX A- MOISTURE ADSORPTION DATA

A.1 Moisture Adsorption in Dynamic Environment

Table A.1 Estimated parameters of moisture adsorption models for feed-grade pea.

Temperature	RH	Peleg model		Page model		Diffusion model		Two-term exponential model			
(C)	(%)	k1	k2	k	N	A	B	A0	A1	K1	K2
10	60	16.9924	0.3819	0.0004	1.0543	0.0007	0.9793	0.9686	0.0314	0.0006	0.0638
10	70	5.8050	0.1905	0.0002	1.2219	0.0010	1.0261	0.9717	0.0544	0.0010	0.0010
10	80	16.7171	0.0521	0.0000	1.3222	0.0002	1.0595	1.0035	0.0780	0.0002	0.0002
10	90	8.2576	0.0478	0.0002	1.0199	0.0002	0.9631	0.1000	0.9000	0.0000	0.0003
20	60	6.4000	0.4781	0.0075	0.7127	0.0008	0.8689	0.7735	0.2281	0.0007	0.0173
20	70	4.7412	0.1256	0.0002	1.1969	0.0010	1.0201	1.0340	0.0034	0.0010	0.0982
20	80	3.3557	0.0379	0.0001	1.1172	0.0003	0.9935	0.9918	0.0085	0.0003	0.1018
20	90	6.1041	0.0597	0.0003	1.0009	0.0003	0.9355	0.0831	0.9184	0.0343	0.0003
30	60	5.3402	0.3312	0.0017	0.9346	0.0011	0.9874	0.9802	0.0198	0.0011	0.0483
30	70	2.0925	0.1121	0.0026	0.8367	0.0007	0.9289	0.1229	0.8760	0.0090	0.0007
30	80	1.1839	0.0538	0.0009	0.9831	0.0008	0.9843	0.0200	0.9799	0.1787	0.0008
30	90	0.6623	0.0198	0.0003	1.0857	0.0006	1.0065	0.0089	1.0081	0.0686	0.0006
40	60	2.4380	0.1813	0.0044	0.7894	0.0009	0.8996	0.8435	0.1505	0.0008	0.0147
40	70	1.3363	0.1153	0.0039	0.8245	0.0010	0.9246	0.7855	0.2073	0.0009	0.0052
40	80	0.6303	0.0495	0.0011	1.0309	0.0013	1.0090	0.8748	0.1342	0.0013	0.0013
40	90	0.4556	0.0207	0.0007	1.0232	0.0009	1.0060	0.7755	0.2304	0.0009	0.0009

Table A.2 Estimated parameters of moisture adsorption models for clean pea.

Temperature	RH	Peleg model		Page model		Diffusion model		Two term exponential model			
(C)	(%)	k1	k2	k	N	A	B	A0	A1	K1	K2
10*	60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	70	18.9961	0.2534	0.0000	1.6586	0.0008	1.1014	0.8139	0.2875	0.0008	0.0008
10	80	38.4349	0.0250	0.0000	1.5532	0.0002	1.0595	1.0035	0.0780	0.0002	0.0003
10	90	8.7426	0.0865	0.0001	1.1277	0.0003	1.0214	0.1978	0.8237	0.0003	0.0002
20	60	18.4085	4.4394	0.0195	0.6804	0.0023	0.8718	0.2805	0.7195	0.1706	0.0018
20	70	18.8234	0.0585	0.0000	1.7596	0.0008	1.1107	1.1740	0.0174	0.0009	0.0808
20	80	3.9788	0.0487	0.0000	1.3168	0.0004	1.0977	0.1238	1.1238	1.8403	0.0004
20	90	12.7844	0.0874	0.0000	1.2803	0.0003	1.1277	1.1006	0.0158	0.0003	0.3984
30	60	9.3409	1.4015	0.0000	2.2452	0.0032	1.1404	0.8687	0.2471	0.0029	0.0029
30	70	4.3147	0.1336	0.0003	1.1291	0.0007	1.0305	0.0049	1.0391	0.0665	0.0007
30	80	1.3950	0.0660	0.0005	1.0772	0.0009	1.0170	0.4291	0.5879	0.0009	0.0009
30	90	0.9136	0.0221	0.0002	1.1347	0.0006	1.0065	0.0794	1.0793	0.0689	0.0005
40	60	9.5813	0.8798	0.0024	0.9147	0.0013	0.9578	0.9326	0.0806	0.0012	0.1422
40	70	2.4893	0.1865	0.0013	0.9854	0.0011	0.9932	0.0127	0.9872	0.0985	0.0011
40	80	1.0432	0.0704	0.0004	1.1671	0.0013	1.0676	0.8864	0.1812	0.0013	0.0013
40	90	0.5310	0.0226	0.0028	0.7823	0.0005	0.9172	0.3371	0.6701	0.0019	0.0003

*There was no change in weight of the samples at 10°C and 60% RH, as a result there was no data and consequently no model parameters at this condition of temperature and RH.

A.2 Moisture Adsorption of Clean and Feed Peas during Storage in Static Environment.

Table A.3 MC and RH of feed-grade and clean peas during storage at 10°C and 60% RH.

10, 60%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	64.2	9.60	60.0	10.35	62.3	10.35	64.6
7	11.27	57.7	11.33	57.1	11.42	55.7	11.41	59.0
14	11.89	58.5	11.97	58.6	12.16	56.2	12.06	59.3
21	12.42	59.0	12.47	59.4	12.79	58.1	12.67	59.0
28	12.71	59.1	12.70	59.6	13.09	58.7	12.96	59.3
35	12.96	59.9	12.93	60.2	13.34	59.1	13.22	59.6
42	13.18	60.9	13.11	61.6	13.53	60.4	13.44	61.2
49	13.53	62.5	13.49	62.0	13.95	62.3	13.87	61.4
56	13.65	60.9	13.64	61.3	14.10	60.8	14.00	60.4
63	13.67	60.6	13.65	61.5	14.13	60.7	14.05	60.0
70	13.75	60.9	13.72	61.0	14.23	60.7	14.13	60.0
77	13.73	61.2	13.69	61.2	14.23	61.4	14.13	60.7
84	13.71	60.8	13.73	61.5	14.24	61.0	14.14	60.1
91	13.78	60.6	13.71	62.0	14.31	61.0	14.20	60.0
99	13.78	60.5	13.74	61.5	14.32	60.9	14.22	60.0
106	13.81	60.3	13.83	61.4	14.36	60.7	14.27	59.7
114	13.84	60.9	13.86	61.4	14.40	61.0	14.30	60.4
120	13.90	60.6	13.90	61.4	14.43	60.3	13.87	59.7
127	13.91	60.4	13.91	60.9	14.47	60.3	13.89	60.5
134	13.91	61.3	13.91	60.9	14.47	60.7	13.85	59.6
142	13.91	60.7	13.89	61.1	14.45	60.4	13.90	60.8
149	13.91	59.4	13.89	59.6	14.45	58.5	13.89	59.5
156	13.91	61.9	13.89	62.2	14.46	61.1	13.89	61.2
163	13.91	60.4	13.89	60.7	14.45	59.9	13.89	60.7
Mean RH		60.6		60.8		60.1		60.3

Table A.4 MC and RH of feed-grade and clean peas during storage at 10°C and 70% RH.

10, 70%	F3		F4		C3		C4	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	57.4	9.60	58.5	10.35	60.3	10.35	57.5
7	12.71	66.1	12.39	66.1	12.45	68.3	12.75	68.1
14	14.11	67.9	13.53	66.3	13.92	69.3	14.30	70.1
21	14.85	70.0	14.37	70.1	15.33	70.2	15.29	70.8
28	15.11	69.9	14.71	68.9	16.15	70.4	15.88	72.5
35	16.04	72.8	15.29	71.0	16.68	73.5	16.29	73.0
42	16.22	72.7	15.76	72.7	17.00	73.7	16.68	74.0
49	16.38	70.3	16.07	71.6	17.31	71.8	16.96	72.4
56	16.57	73.3	16.14	73.0	17.49	74.2	17.12	73.6
63	16.60	72.4	16.12	72.7	17.53	74.3	17.14	74.0
70	16.69	71.5	16.42	72.3	17.63	73.1	17.27	73.2
77	16.65	70.6	16.27	72.0	17.51	72.8	17.16	72.8
84	16.63	71.2	16.19	72.0	17.38	72.7	17.03	72.8
91	16.63	71.1	16.14	72.0	17.23	71.7	16.94	73.1
98	16.88	72.8	16.28	72.2	17.42	72.7	17.12	73.5
105	16.88	70.0	16.28	70.0	17.43	71.3	17.11	71.3
112	16.88	70.3	16.24	70.3	17.37	71.7	17.06	71.6
119	16.88	68.0	16.24	68.0	17.37	71.2	17.10	70.1
126	16.88	72.2	16.20	71.3	17.32	72.1	17.05	70.5
133	17.04	71.7	16.20	70.3	17.31	71.1	17.03	70.0
140	17.01	71.6	16.22	71.1	17.32	71.2	17.03	70.7
148	17.01	71.4	16.19	71.1	17.29	71.2	17.01	70.6
155	17.07	71.1	16.21	71.2	17.32	71.0	17.03	70.8
163	17.08	71.7	16.21	71.0	17.35	71.2	17.04	70.7
169	17.10	71.2	16.21	71.0	17.38	71.2	17.10	70.7
176	17.11	71.0	16.23	70.2	17.39	70.5	17.09	70.5
183	17.06	70.2	16.20	70.0	17.37	70.4	17.09	70.4
191	17.07	69.0	16.20	68.2	17.37	69.2	17.03	69.2
198	17.05	70.0	16.19	69.5	17.34	70.1	17.07	69.0
205	17.07	71.0	16.19	68.9	17.29	69.5	17.03	67.0
212	17.08	69.2	16.19	68.5	17.32	68.5	17.03	66.5
Mean RH		70.3		70.1		71.0		70.7

Table A.5 MC and RH of feed-grade and clean pea during storage at 10°C and 80% RH.

10, 80%	F5		F6		C5		C6	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
1	9.60	66.5	9.60	70.8	10.35	70.9	10.35	71.1
8	13.35	71.5	14.21	76.8	14.04	76.4	13.57	74.8
15	15.51	75.5	17.41	77.9	17.37	78.4	16.21	76.4
22	18.11	80.0	19.19	80.9	18.81	80.5	18.31	78.3
29	19.49	80.1	20.21	80.2	19.68	80.0	19.72	80.2
36	20.48	80.9	21.17	81.6	20.58	81.1	20.79	80.3
43	20.80	82.4	21.98	83.1	21.15	81.8	21.48	82.4
50	21.17	81.4	22.57	82.1	21.57	82.0	21.92	81.9
57	21.49	82.3	22.89	83.3	21.86	82.1	22.22	82.4
64	21.71	81.1	23.03	83.0	21.97	82.1	22.42	82.7
71			22.53	83.0	22.24	82.4	22.56	82.6
78					22.60	83.3	22.58	82.7
85					22.60	83.1	22.69	82.9
92					22.64	82.1	22.85	82.9
99					22.89	83.1	23.11	82.7
106					22.98	83.5	23.15	82.7
113					23.00	81.8	23.15	82.7
120					22.95	81.7	22.95	81.4
Mean RH		78.2		80.2		80.9		80.6

Table A.6 MC and RH of feed-grade and clean peas during storage at 10°C and 90% RH.

10, 90%	F7		F8		C7		C8	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	85.0	9.60	86.4	10.35	86.0	10.35	89.0
7	15.26	69.5	12.42	70.2	15.30	70.0	13.98	76.7
14	17.22	70.5	14.26	72.1	17.19	72.0	17.00	78.0
21	18.84	74.5	15.84	74.4	18.69	73.7	19.17	80.7
28	20.04	77.3	17.27	77.7	19.94	76.6	20.15	81.2
35	20.87	80.1	18.11	77.5	20.81	75.9	21.56	82.6
42	21.63	80.4	18.79	80.1	21.49	79.8	22.17	84.6
49	22.19	81.4	19.31	80.8	22.04	80.4	22.48	84.7
56	22.60	82.4	20.18	81.7	23.04	81.6	23.00	84.8
63	22.87	82.6	20.67	81.9	23.46	81.6	23.33	84.9
70	23.27	82.8	21.15	82.6	23.91	82.1	24.37	85.5
77	24.06	82.7	21.79	82.6	24.51	82.7	24.55	85.5
84	24.48	83.7	22.62	84.8	25.02	83.9	24.89	85.8
91	24.88	84.6	23.15	85.7	25.57	84.3	25.04	85.8
98	25.17	84.8	23.61	86.0	25.98	84.9	25.20	86.5
105	25.44	85.0	23.89	86.2	26.29	85.0	25.32	86.5
111					26.85	85.9		
118					27.32	86.5		
126					27.71	86.5		
Mean RH		80.5		80.7		81.0		83.9

Table A.7 MC and RH of feed-grade and clean peas during storage at 20°C and 60% RH.

20, 60%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	50.0	9.60	54.80	10.35	51.0	10.35	49.6
7	11.08	53.1	11.32	55.80	11.61	52.1	11.41	49.8
14	11.87	55.2	11.64	56.90	12.35	56.4	12.16	54.2
21	12.26	56.5	12.84	60.90	12.74	57.2	12.48	56.2
28	12.59	57.9	13.55	63.40	13.02	58.3	12.77	56.3
35	12.56	59.2	13.75	65.30	13.02	59.5	12.77	58.6
42	12.98	58.8	14.26	65.50	13.43	59.2	13.25	57.4
49	12.98	59.9	14.44	66.70	13.52	59.5	13.42	59.6
56	13.13	59.2	14.53	66.00	13.58	59.5	13.43	58.1
63	13.17	59.5	13.98	62.30	13.61	59.2	13.43	58.2
70	13.24	59.5	13.83	60.90	13.68	60.0	13.53	59.5
77	13.19	60.0	13.66	61.20	13.64	59.8	13.53	59.1
84	13.15	59.5	13.51	60.00	13.85	59.1	13.47	59.9
91	13.05	60.2	13.40	60.00	13.69	60.7	13.44	60.1
98	13.32	58.7	13.69	59.70	14.02	59.3	13.73	59.1
105	13.42	60.5	13.73	60.90	14.06	60.4	13.76	60.8
112	13.39	59.6	13.69	59.50	14.04	59.1	13.74	59.1
119	13.39	60.3	13.67	60.00	14.05	59.5	13.69	58.6
126	13.35	59.2	13.63	59.70	13.96	59.5	13.61	58.5
133	13.40	58.6	13.72	58.90	14.04	58.9	13.76	58.5
140	13.36	59.2	13.66	59.40	14.02	59.3	13.72	58.5
147	13.36	59.9	13.63	60.10	13.97	59.0	13.70	59.1
155	13.37	59.9	13.61	60.00	14.01	59.3	13.55	58.9
160	13.41	59.8	13.63	59.70	13.98	60.9	13.66	59.3
168	13.40	59.5	13.62	59.60	13.99	60.4	13.60	59.3
174	13.40	58.8	13.64	59.20	14.01	59.1	13.60	57.5
181	13.41	58.7	13.64	59.00	14.02	58.9	13.59	56.9
188	13.41	58.9	13.64	58.90	14.01	59.6	13.59	57.1
195	13.42	58.8	13.62	58.70	14.01	59.1	13.58	57.0
202	13.43	58.5	13.62	58.50	14.01	58.6	13.58	56.8
209	13.43	59.3	13.63	59.30	14.01	59.3	13.55	57.4
216	15.50%	58.0	13.63	58.50	14.01	58.5	13.57	56.2
Mean RH		58.6		60.29		58.8		57.7

Table A.8 MC and RH of feed-grade and clean pea during storage at 20°C and 70% RH.

20, 70%	F3		F4		C3		C4	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	65.0	9.60	61.9	10.35	61.0	10.35	63.3
7	13.30	67.1	12.96	65.2	12.50	62.3	13.12	65.1
14	14.53	69.6	14.30	67.9	13.28	65.1	14.75	69.4
21	15.22	70.4	15.11	68.6	14.32	65.9	15.67	70.1
28	15.61	71.3	15.68	70.9	15.10	68.1	16.07	70.7
35	15.65	73.0	17.22	73.2	15.53	68.9	16.08	73
42	16.05	73.3	17.65	73.9	16.07	71.7	16.55	72.9
49	16.12	72.9	17.69	74.5	16.31	72.6	16.65	73.3
56	16.22	72.1	17.63	72.2	16.51	71.9	16.87	72.6
63	16.22	72.2	17.64	72.6	16.56	72.0	16.88	72.7
70	16.24	72.3	17.63	72.8	16.62	72.4	16.93	72.9
77	16.17	72.2	17.55	72.2	16.59	72.1	16.84	72.5
84	16.08	72.8	17.44	73.0	16.26	72.2	16.50	72.5
91	15.99	73.7	17.37	73.7	16.15	72.9	16.43	72.9
98	16.30	72.5	17.66	72.4	16.44	72.1	16.72	72.1
105	16.34	72.7	17.66	72.6	16.48	72.4	16.75	72.4
112	16.31	72.4	17.67	72.7	16.45	71.8	16.73	71.8
119	16.33	72.1	17.64	72.1	16.43	71.8	16.73	71.8
126	16.29	72.5	17.62	72.5	16.43	72.5	16.78	72.6
133	16.35	71.8	17.71	72.1	16.50	72.1	16.78	71.9
140	16.31	71.9	17.65	71.7	16.42	71.5	16.68	71.9
147	16.27	72.9	17.59	72.5	16.42	71.9	16.66	72.6
155	16.30	72.2	17.59	72.3	16.40	71.5	16.69	72.6
160	16.31	71.9	17.61	72.0	16.43	71.6	16.69	72.6
168	16.31	72.1	17.60	72.2	16.45	72.1	16.69	72.4
174	16.32	71.7	17.62	71.9	16.45	71.4	16.70	71.8
181	16.29	71.4	17.62	71.5	16.45	70.9	16.70	71.8
188	16.29	71.8	17.62	72.1	16.45	71.8	16.70	72.1
195	16.28	71.0	17.59	71.2	16.45	70.6	16.67	71.2
202	16.34	71.0	17.62	70.6	16.47	70.5	16.70	71.3
209	16.32	71.6	17.61	71.6	16.45	71.3	16.59	72.1
216	16.34	71.8	17.63	72.0	16.49	70.0	16.70	70.7
Mean RH		71.7		71.5		70.5		71.55

Table A.9 MC and RH of feed-grade and clean peas during storage at 20°C and 80% RH.

20, 80%	F5		F6		C5		C6	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	57.9	9.60	65.5	10.35	68.2	10.35	66.8
7	13.72	62.8	12.59	67.2	14.43	70.2	12.85	68.2
14	16.02	75.2	14.40	69.8	17.03	76.6	14.85	70.6
21	17.68	77.8	15.71	73.5	18.77	79.1	16.40	74.5
28	18.59	79.8	16.70	75.0	19.74	80.7	17.42	75.8
35	19.06	80.1	17.15	76.7	20.08	81.1	17.92	77.6
42	19.76	81.1	17.90	78.1	21.07	82.6	18.65	78.8
49	20.09	82.6	18.30	78.1	21.44	83.0	19.01	79.7
56	20.32	81.7	18.54	79.5	21.65	83.3	19.22	79.6
63			18.78	78.3	21.94	82.9	19.43	79.2
69					22.10	83.1	19.61	80.1
76					21.76	82.4	19.65	79.8
83							19.65	79.5
90							19.73	82.0
Mean RH		75.4		74.2		79.4		76.6

Table A.10 MC and RH of feed-grade and clean peas during storage at 20°C and 90% RH.

20, 90%	F7		F8		C7		C8	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	89.7	9.60	92.3	10.35	88.4	10.35	89.0
7	14.66	73.9	14.78	73.9	13.96	73.5	15.06	74.2
14	17.58	76.9	17.56	79.0	16.81	76.7	18.26	78.3
21	19.47	81.0	19.21	81.1	18.71	80.3	21.02	82.7
28	20.84	83.4	20.59	83.5	20.39	82.5	22.85	84.5
35	21.73	84.7	21.48	84.6	21.13	84.0	23.84	86.0
42					22.15	84.5		
Mean RH		81.6		82.4		81.4		82.5

Table A.11 MC and RH of feed-grade and clean peas during storage at 30°C and 60% RH.

30, 60%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	67.7	9.60	67.1	10.35	60.0	10.35	66.3
7	11.36	55.4	11.34	55.3	12.04	55.0	11.94	55.0
14	11.83	57.5	11.82	56.5	12.57	56.0	12.46	56.8
21	11.92	57.9	11.93	57.3	12.77	58.6	12.59	57.1
28	11.76	57.2	11.75	57.3	12.63	57.4	12.41	57.5
35	11.96	57.9	11.99	57.7	12.87	58.3	12.67	57.5
42	11.66	57.6	11.69	58.0	12.58	58.0	12.35	57.8
49	12.11	57.7	12.14	58.1	13.02	58.3	12.81	58.1
56	12.15	57.5	12.20	57.7	13.09	57.7	12.86	57.6
63	12.12	58.0	12.16	57.9	13.06	58.2	12.83	58.1
70	12.17	58.4	12.21	58.2	13.10	58.0	12.87	58.1
77	12.07	57.7	12.15	58.2	13.06	58.3	12.78	58.1
84	12.09	57.5	12.18	57.2	13.07	58.0	12.83	57.2
91	12.06	57.2	12.09	57.4	13.02	57.8	12.79	57.6
98	12.06	57.8	12.13	58.1	13.00	58.2	12.77	58.0
105	12.13	57.9	12.18	58.4	13.11	58.5	12.86	58.4
113	12.04	57.9	12.12	57.8	13.00	57.8	12.80	57.7
119	12.03	57.9	12.09	58.1	12.98	58.3	12.74	58.2
126	12.16	57.4	12.22	58.1	13.11	58.5	12.89	58.0
133	12.09	57.9	12.17	59.0	13.07	58.4	12.82	58.8
140	12.08	57.1	12.20	58.0	13.14	58.1	12.83	57.7
148	12.08	56.2	12.18	56.4	13.10	56.6	12.79	56.9
154	12.06	57.9	12.12	58.1	13.10	57.9	12.78	58.0
162	12.07	57.4	12.14	57.8	13.10	57.4	12.77	58.0
Mean RH		57.9		58.1		57.9		58.0

Table A.12 MC and RH of feed-grade and clean peas during storage at 30°C and 70% RH.

30, 70%	F3		F4		C3		C4	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	78.1	9.60	79.6	10.35	80.6	10.35	77.2
7	13.29	65.6	12.98	65.1	13.43	64.6	13.32	63.4
14	14.17	68.1	14.00	67.6	14.55	67.7	14.53	67.2
21	14.25	69.9	14.17	69.4	14.79	69.4	14.79	69.9
28	14.55	70.0	14.57	70.4	15.14	70.1	15.15	70.0
35	14.29	70.3	14.26	70.7	14.91	70.8	14.90	70.1
42	14.76	70.3	14.73	70.5	15.34	70.4	15.35	70.6
49	14.83	70.4	14.82	70.5	15.40	70.7	15.44	70.5
56	14.79	71.7	14.77	71.0	15.31	70.9	15.40	71.0
63	14.83	71.1	14.82	70.8	15.40	70.9	15.43	70.8
70	14.77	71.5	14.30	70.4	15.41	70.5	15.40	70.6
77	14.79	70.6	14.46	70.0	15.41	70.2	15.37	70.0
84	14.75	70.4	14.42	69.9	15.34	69.9	15.33	69.8
92	14.70	70.6	14.43	70.0	15.30	70.0	15.31	70.0
99	14.82	71.0	13.87	67.0	14.81	68.0	15.38	70.4
107	14.75	70.2	14.25	69.8	15.22	69.8	15.34	70.0
113	14.73	71.8	14.30	70.1	15.24	70.9	15.28	70.6
120	14.85	71.4	14.46	70.4	15.38	70.6	15.42	70.6
127	14.93	70.2	14.42	70.0	15.38	70.2	15.34	70.1
134	14.84	70.3	14.46	69.7	15.40	70.0	15.38	69.9
142	15.04	70.1	14.40	70.1	15.43	70.3	15.29	70.0
148	15.04	70.1	14.40	69.5	15.46	70.0	15.29	70.0
156	14.92	70.0	14.42	70.0	15.48	70.0	15.29	70.0
Mean RH		70.6		70.1		70.3		70.1

Table A.13 MC and RH of feed-grade and clean peas during storage at 30°C and 80% RH.

30, 80%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	79.3	9.60	78.4	10.35	80.4	10.35	79.3
4	12.84		12.55		12.35		12.93	
7	14.13	71.4	13.89	70.7	13.67	72.8	14.16	70.2
11	15.50		15.30		15.08		15.63	
14	16.21	74.6	15.71	75.2	15.83	74.3	16.32	75.2
18	16.74		16.41		16.29		16.89	
21	16.90	78.0	16.62	77.8	16.46	77.0	17.02	77.3
25	17.19	79.1	16.97	79.7	16.84	79.6	17.37	79.1
28	17.27		17.09		16.94		17.50	
31	17.42	79.0	17.27	78.2	17.08	78.9	17.66	78.5
34	17.46		17.32		17.17		17.72	
37					17.44		17.96	
40					17.54	78.4	18.07	79.0
46					17.60	79.1	18.11	78.8
53					17.69	79.1	18.17	79.4
Mean RH		76.9		76.7		77.7		77.4

Table A.14 MC and RH of feed-grade and clean peas during storage at 30°C and 90% RH.

30, 90%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	89.6	9.60	86.1	10.35	87.8	10.35	86.8
4	13.86		13.73		13.92		12.69	
7	15.97	80.6	15.66	77.2	15.99	76.4	15.23	75.6
11	17.98		17.63		17.71		17.44	
14	19.10	82.1	18.70	79.8	18.81	80.6	18.70	79.5
18	20.14		19.76		19.86		19.98	
21	20.64	84.5	20.17	83.4	20.33	83.7	20.48	83.7
25	21.34	86.5	20.86	85.6	21.15	85.1	21.32	85.4
28					21.54		21.72	
31					21.97	85.1	22.19	85.6
Mean RH		84.7		82.4		83.1		82.8

Table A.15 MC and RH of feed-grade and clean peas during storage at 40°C and 60% RH.

40, 60%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	62.4	9.62	63.8	10.35	66.1	10.35	62.5
6	11.90	60.8	12.06	60.3	13.38	65.8	12.56	60.8
13	11.99	61.2	12.24	61.8	13.87	66.7	12.72	60.9
20	12.31	61.8	12.69	63.0	14.33	68.2	13.09	62.6
27	12.32	60.6	12.43	61.8	13.90	64.3	13.09	60.6
34	12.32	60.5	12.48	61.2	13.82	64.1	13.04	60.6
41	12.01	60.8	12.20	61.3	13.54	64.3	12.77	61.0
48	12.20	61.2	12.37	61.9	13.71	64.5	13.18	61.3
55	12.78	60.6	12.89	61.2	14.11	64.3	13.73	60.7
62	12.82	60.3	12.91	60.9	14.08	63.6	13.73	61.8
69	12.78	60.5	12.88	60.2	14.04	63.2	13.69	60.4
76	12.80	61.5	12.75	60.5	13.95	63.5	13.54	60.9
83	12.80	60.7	12.78	60.9	13.95	64.0	13.70	61.0
90	12.85	60.2	12.92	61.4	14.07	63.6	13.72	60.7
97	12.86	60.4	12.93	60.5	14.04	64.0	13.73	60.9
104	12.84	60.6	12.95	62.1	13.52	60.5	13.68	61.2
112	12.80	60.8	12.88	61.0	13.40	60.0	13.59	61.2
117	12.76	61.1	12.91	60.9	12.80	59.3	13.64	61.2
125	12.81	59.9	12.89	60.9	13.33	59.5	13.60	60.2
131	12.81	59.6	12.91	59.9	13.38	58.7	13.65	59.7
138	12.72	61.9	12.80	62.1	13.25	59.6	13.51	62.0
145	12.72	59.8	12.88	50.1	13.27	58.7	13.59	60.2
152	12.73	59.6	12.91	59.9	13.28	58.7	13.58	60.7
160	12.62	58.9	12.84	59.3	13.15	58.3	13.46	59.5
166	12.72	60.9	12.91	61.2	13.28	59.5	13.53	62.1
174	12.64	61.7	12.81	61.1	13.20	59.2	13.50	60.4
Mean RH		60.7		60.7		62.4		61.0

Table A.16 MC and RH of feed-grade and clean peas during storage at 40°C and 70% RH.

40, 70%	F3		F4		C3		C4	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	73.0	9.60	72.3	10.35	68.5	10.35	77.0
6	13.80	71.3	13.70	68.6	13.46	65.7	14.97	71.9
13	14.32	71.7	14.18	71.0	13.93	68.2	15.79	75.0
20	14.84	71.5	14.72	71.2	14.52	69.0	16.36	75.5
27	14.84	71.5	14.72	71.2	14.39	68.2	15.77	72.8
34	14.76	71.6	14.66	71.7	14.35	67.7	15.55	72.7
41	14.52	71.1	14.38	70.9	14.08	68.1	15.23	72.8
48	14.68	72.3	14.60	72.2	14.85	68.6	15.48	73.3
55	15.23	71.9	15.21	72.2	15.32	68.5	15.85	72.1
62	15.15	72.2	15.18	71.8	15.26	70.3	15.77	71.8
69	15.19	71.6	15.10	71.4	15.27	68.2	15.73	71.6
76	15.07	71.5	14.94	71.6	15.11	68.0	15.59	71.1
83	14.95	71.9	14.98	71.9	15.16	68.6	15.66	71.6
90	15.08	71.1	15.04	71.4	15.22	67.7	15.68	71.4
97	15.06	71.2	15.04	71.7	16.14	72.5	15.66	71.3
104	15.03	71.7	14.98	71.8	15.97	71.7	15.58	71.9
112	14.97	71.5	14.90	71.8	15.92	71.1	15.56	71.8
117	15.02	71.3	15.02	71.7	15.93	71.0	15.58	71.7
125	14.93	71.1	14.91	70.3	15.87	70.7	15.53	70.6
131	14.95	71.4	14.90	71.4	15.90	71.2	15.58	70.4
138	14.84	71.8	14.82	71.8	15.80	71.2	15.43	71.3
145	14.95	71.2	14.87	70.5	15.87	70.8	15.46	70.3
152	15.00	71.3	14.82	72.0	15.86	72.8	15.44	73.1
160	14.81	70.3	14.67	70.9	15.72	71.8	15.34	70.2
166	14.88	71.3	14.82	71.5	15.82	70.9	15.44	71.0
174	14.78	70.6	14.79	70.9	15.71	70.6	15.44	70.8
Mean RH		71.5		71.4		69.7		72.1

Table A.17 MC and RH of feed-grade and clean peas during storage at 40°C and 80% RH.

40, 80%	F1		F2		C1		C2	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	74.1	9.60	77.4	10.35	69.8	10.35	71.7
4	11.38		11.86		11.31		11.42	
7	13.38	70.2	12.56	65.1	12.16	72.7	13.52	69.5
11	14.67		15.36		15.11		14.90	
14	15.12	73.0	16.62	76.6	15.68	73.8	15.54	73.8
18	15.95		18.85		16.64		16.38	
21	16.52	78.1	18.52	82.2	17.04	78.5	16.88	78.2
25	16.95	80.2	19.11		17.33	79.4	17.20	79.4
28	17.20		19.28	84.0	17.56		17.51	
31	17.20	80.7			17.50	80.7	17.42	80.7
34	17.15	80.7			17.46		17.35	
37					17.97	81.2	17.88	80.0
39					17.81		17.71	
42					18.06	80.9	17.87	80.2
46					17.79		17.62	
53					17.91	80.9	17.77	81.2
Mean RH		76.7		77.1		77.5		77.2

Table A.18 MC and RH of feed-grade and clean peas during storage at 40°C and 90% RH.

40, 90%	F3		F4		C3		C4	
Number of days	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)	MC (% w.b.)	RH (%)
0	9.60	87.2	9.60	88.4	10.35	87.7	10.35	82.3
4	14.75		16.60		16.26		15.32	
7	17.50	80.9	20.05	87.2	19.78	78.5	18.22	75.5
11	18.93		21.29		22.33		19.99	
14	20.41	86.5	22.11	87.7	23.58	90.0	20.77	84.3
18					24.72	89.1	21.79	
21							21.87	89.6
Mean RH		84.9		87.8		86.3		82.9

Table A.19 Mean RH and standard deviation for both feed-grade and clean peas during storage.

	Feed-grade Pea		Clean Pea	
Temperature (°C)	Mean RH (%)	Standard deviation	Mean RH (%)	Standard deviation
10	60.6	1.30	60.1	1.60
	60.8	1.20	60.3	1.10
	70.3	2.86	71.0	2.52
	70.1	2.77	70.7	3.11
	78.2	5.34	80.9	3.07
	80.2	3.81	80.6	3.37
	80.5	4.98	81.0	5.09
	80.7	5.07	83.9	3.27
20	58.6	2.20	58.8	2.10
	60.3	2.70	57.7	2.50
	71.7	2.90	70.5	2.90
	71.5	2.10	71.6	2.10
	75.4	8.92	79.4	5.19
	74.2	5.02	76.6	4.79
	81.6	5.66	81.4	5.04
	82.4	6.16	82.5	5.39
30	57.9	2.20	57.9	1.00
	58.1	2.10	58.0	1.90
	70.6	2.10	70.3	2.60
	70.1	2.50	70.1	2.20
	76.9	3.22	77.7	2.57
	76.7	3.27	77.2	3.02
	84.7	3.57	83.1	4.04
	82.4	3.83	82.8	4.34
40	60.7	0.80	62.4	2.90
	60.7	2.40	61.0	0.80
	71.5	0.50	69.7	1.80
	71.4	0.80	72.1	1.60
	76.7	4.26	77.5	4.30
	77.1	7.38	77.2	4.36
	84.9	3.45	86.3	5.30
	87.8	0.60	82.9	5.83

A.3 Moisture Adsorption Data of Feed Pea Components

Table A.20 MC and RH data for whole green pea at 40°C and 90%RH.

Whole Green Pea	G1		G2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	9.60	96.6	9.60	95.5
2	14.87	80.1	13.98	79.3
5	20.39	82.6	19.34	81.1
7	22.16	84.9	21.35	83.1
9	23.43	86.9	22.53	86.0
12	24.91	87.2	23.86	85.9
14			24.46	88.5
Mean RH		86.4		85.6

Table A.21 MC and RH data for Shrivelled yellow and green peas at 40°C and 90%RH.

Shriveled pea	S1		S2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	9.62	92.4	9.62	93.0
4	15.27		14.23	
6	18.30		17.04	
8	19.62	87.6	18.12	84.1
12	21.58		19.88	
15			20.53	86.6
Mean RH		90.0		87.9

Table A.22 MC and RH data for cracked seed coat yellow and green peas at 40°C and 90%RH.

Cracked seed coat	C1		C2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	8.66	88.9	8.66	90.4
4	13.65		13.72	
6	16.01		15.99	
8	17.08	85.0	16.99	83.5
12	18.86		18.48	
15	19.20	90.8	19.10	89.8
Mean RH		88.2		87.9

Table A.23 MC and RH data for split yellow and green peas at 40°C and 90%RH.

Split pea	S1		S2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	8.13	94.4	8.13	93.0
2	16.50	78.7	16.90	79.9
5	19.88	83.1	20.53	84.9
7	20.99	84.8	21.76	86.5
9	21.07	85.9	22.51	86.9
Mean RH		85.4		86.24

Table A.24 MC and RH data for small yellow and green peas at 40°C and 90%RH.

Small pea	S1		S2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b)	RH (%)
0	9.67	85.0	9.67	91.4
6	16.61	81.2	16.01	79.1
8	18.25	83.5	17.93	84.3
12	20.74	87.5	20.94	87.3
15	21.26	87.5	21.51	87.4
Mean RH		84.9		85.9

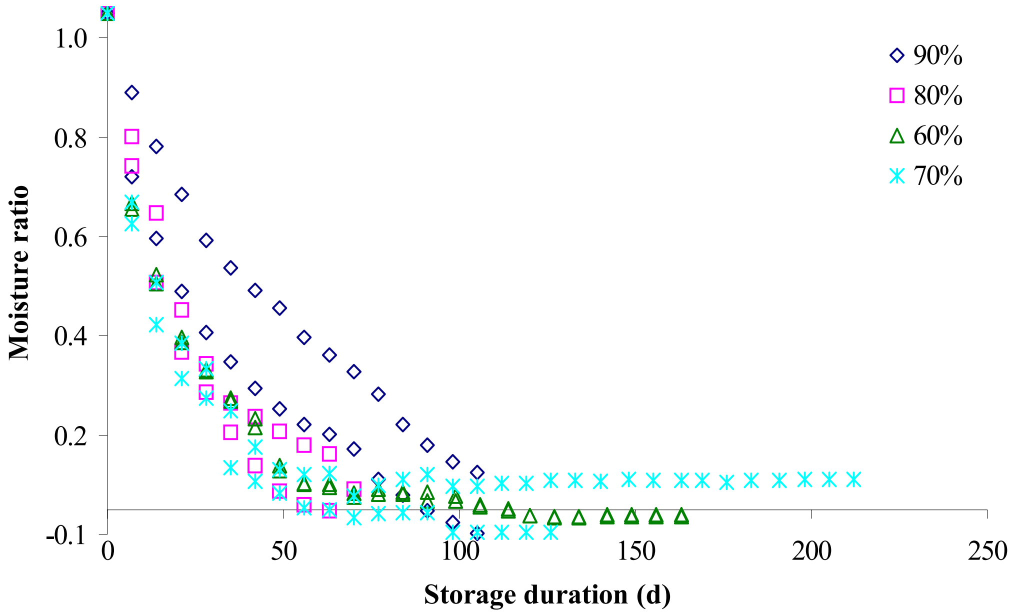
Table A.25 MC and RH data for other damaged yellow and green peas at 40°C and 90%RH.

Other damaged	O1		O2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	8.55	89.4	8.55	86.6
4	17.48	87.5	18.52	88.4
6	21.96		22.36	
Mean RH		88.5		87.5

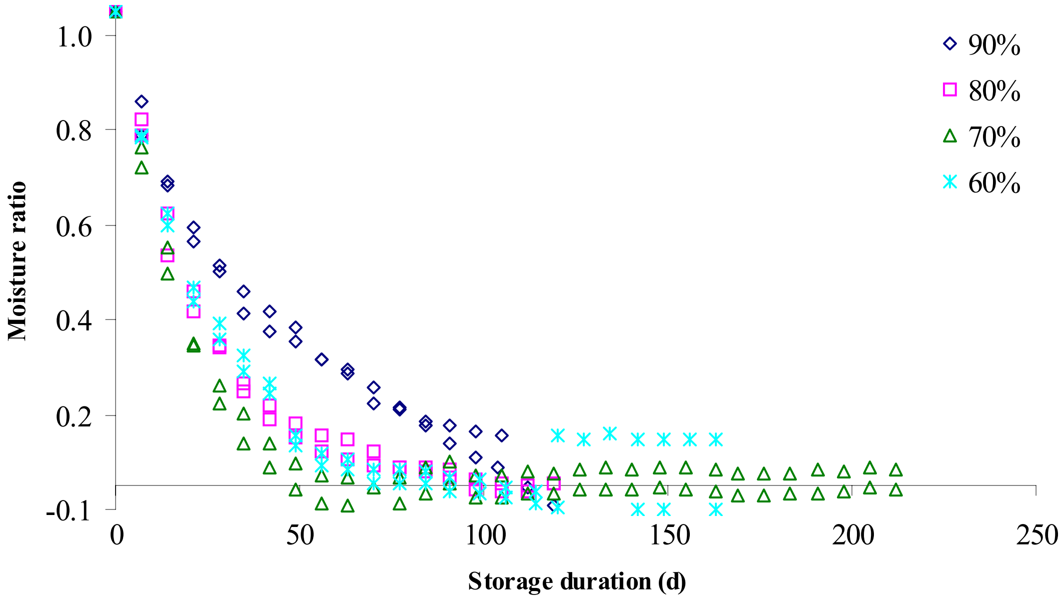
Table A.26 MC and RH data for foreign materials at 40°C and 90%RH.

Foreign material	F1		F2	
Number of days	MC (%.w.b.)	RH (%)	MC (%.w.b.)	RH (%)
0	8.66	85.1	8.66	92.6
4	13.03	80.5	13.56	81.9
6	14.43		15.06	
9	14.61	91.4	15.32	89.6
Mean RH		85.7		88.0

A.3 Moisture Ratio Graphs

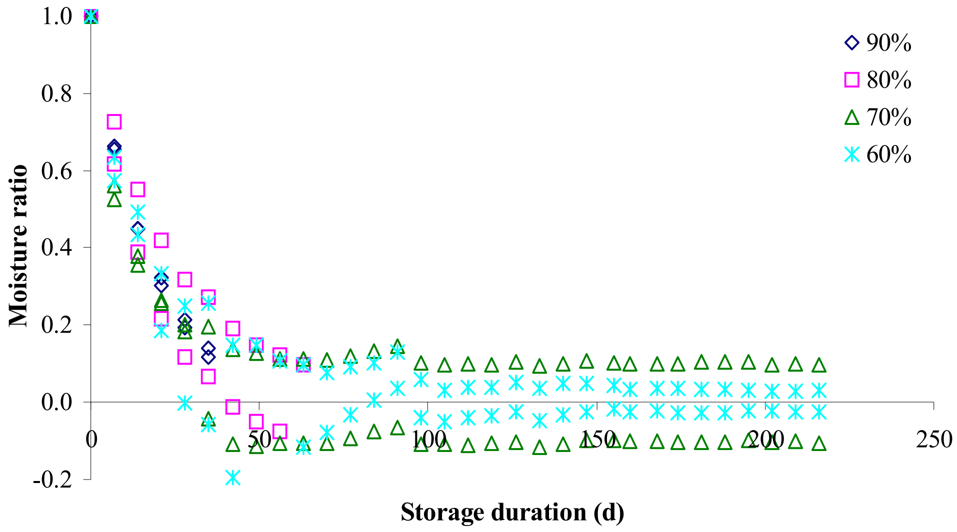


a) Feed pea

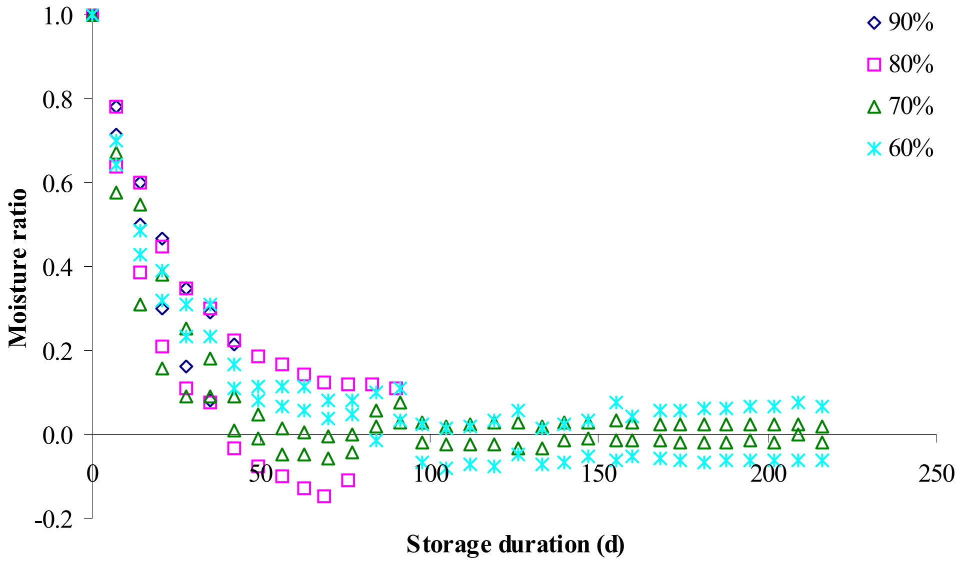


b) Clean pea

Figure A.1 Moisture ratio vs. storage duration for feed pea and clean pea at 10°C.

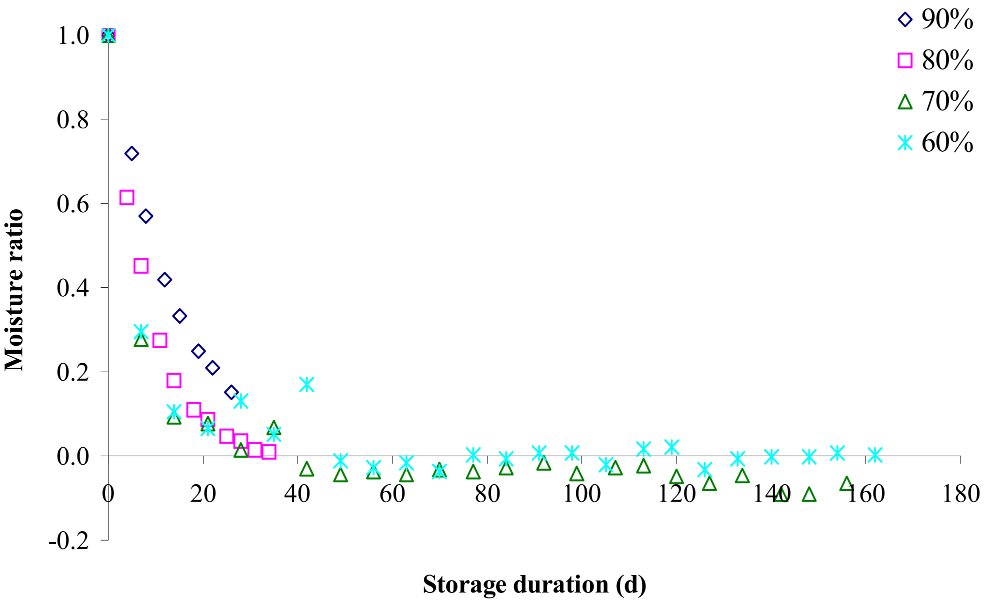


a) Feed pea

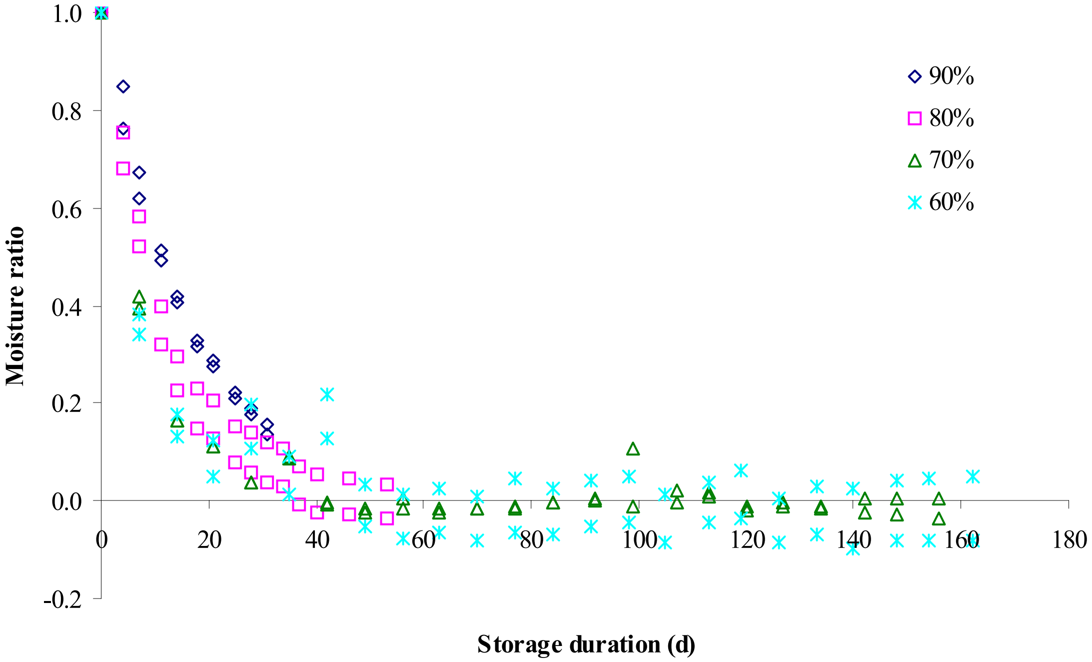


b) Clean pea

Figure A.2 Moisture ratio vs. storage duration for feed pea and clean pea at 20°C.

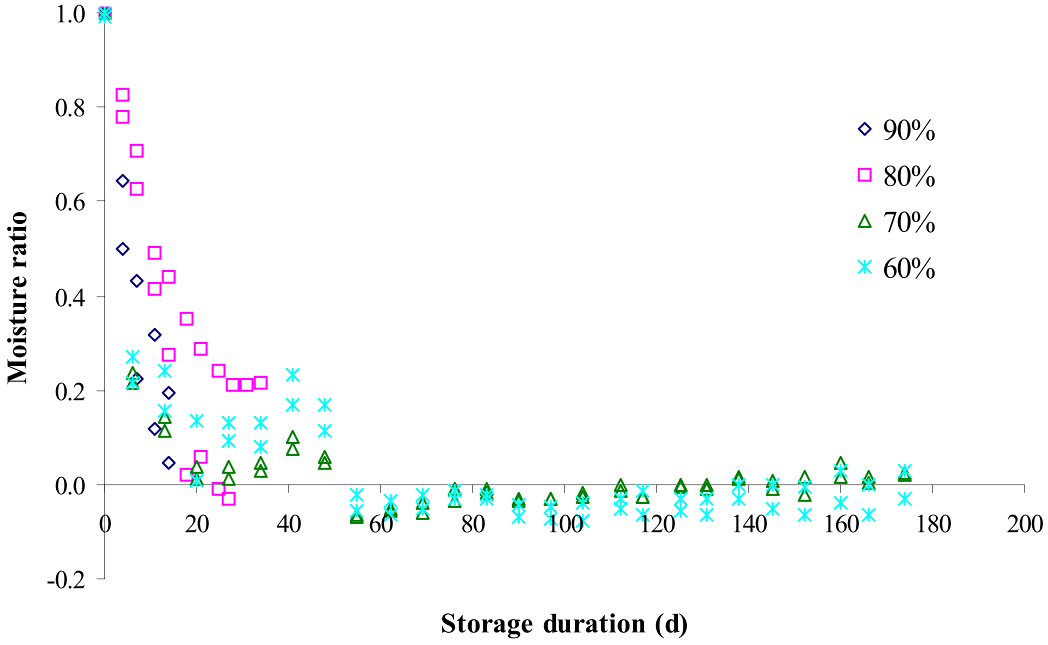


a) Feed pea

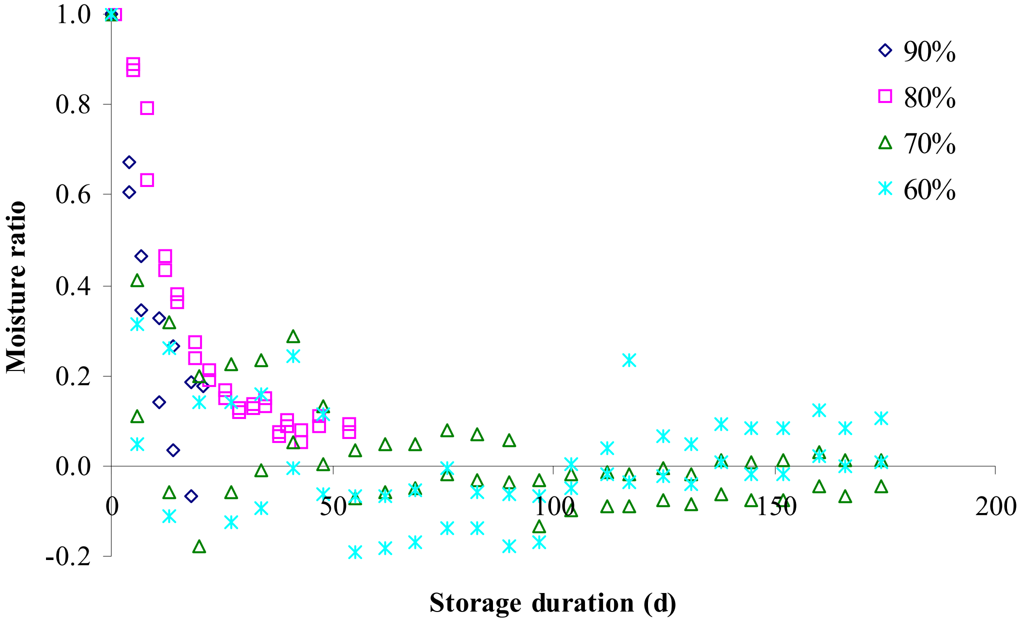


b) Clean pea

Figure A.3 Moisture ratio vs. storage duration for feed pea and clean pea at 30°C.



a) Feed pea



b) Clean pea

Figure A.4 Moisture ratio vs. storage duration for feed pea and clean pea at 40°C.

APPENDIX B – CARBON DIOXIDE MEASUREMENT

Table B.1 Concentration of CO_2 during storage at 10°C and RH of 60 to 90%.

F1		F2		C1		C2	
Time (d)	$CO_{2\,(PPM)}$	Time (d)	$CO_{2\,(PPM)}$	Time (d)	$CO_{2\,(PPM)}$	Time (d)	$CO_{2\,(PPM)}$
10°C, 60%							
3	436.0	23	439.0	3	446.9	23	442.2
56	468.0	86	475.3	86	453.7	56	485.3
132	566.7	132	552.9	132	491.4	132	685.4
163	523.0	163	522.3	163	602.0	163	564.7
10°C, 70%							
21	447.87	29	480.82	21	450.3	29	480.34
52	414.07	105	464.01	72	451.49	105	478.36
119	848.64	136	445.51	136	447.56	181	592.74
181	628.56	181	501.04	181	514.09	212	500.04
212	575.04	212	537.4	212	554.05		
10°C, 80%							
30	421.4	22	397.4	73	443.2	30	394.3
106	615.3	120	598.2	120	508.7	53	378.9
						106	638.6
						120	526.2
10°C, 90%							
68	759.7	15	479.32	68	438.6	35	451.95
98	3894.3	82	1466.7	98	802.78	82	1121.4
		98	3256.8			98	2866.3

* F1- First replication of feed-grade pea

* F2- Second replication of feed-grade pea

* C1- First replication of clean pea

* C2- Second replication of clean pea

Table B.2 Concentration of CO_2 during the storage at 20°C and RH of 60 to 90%.

F1		F2		C1		C2	
Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)
20°C, 60%							
33	535.9	77	610.2	56	531.8	25	449.9
56	721.6	140	633.2	124	538.1	110	802.0
110	808.4	186	650.4	186	610.0	186	713.3
186	751.3	216	625.6	216	558.2	216	495.1
216	527.3						
20°C, 70%							
25	605.9	33	563.8	33	496.0	77	482.8
110	879.3	124	594.8	110	778.1	140	660.4
140	808.0	186	921.9	140	648.4	186	859.3
186	781.8	216	736.2	186	737.8	216	575.9
216	728.9			216	858.5		
20°C, 80%							
25	605.6	25	612.3	33	607.3	76	546.1
56	3494.5	56	2246.5	76	1333.7	90	1429.3
20°C, 90%							
35	1359.9	14	651.89	14	598.8	35	1298.03

* F1- First replication of feed-grade pea

* F2- Second replication of feed-grade pea

* C1- First replication of clean pea

* C2- Second replication of clean pea

Table B.3 Concentration of CO_2 during the storage at 30°C and RH of 60 to 90%.

F1		F2		C1		C2	
Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)	Time (d)	CO_2 (PPM)
30°C, 60%							
3	876.4	23	715.0	3	567.1	23	728.1
56	748.8	86	868.4	56	864.0	70	926.1
131	557.9	131	670.8	131	571.7	128	579.2
162	693.8	162	706.5	162	680.5	162	631.0
30°C, 70%							
49	699.8	16	790.6	16	591.4	49	1028.3
79	798.5	63	915.9	79	626.2	79	743.4
125	875.9	125	725.8	125	638.3	125	627.7
156	505.9	156	670.9	156	580.3	156	635.1
30°C, 80%							
33	1157.6	25	835.0	33	737.3	33	711.6
30°C, 90%							
25	8834.8	25	9050.2	25	1126.5	25	1245.9

* F1- First replication of feed pea

* F2- Second replication of feed pea

* C1- First replication of clean pea

* C2- Second replication of clean pea

Table B.4 Concentration of CO_2 during the storage at 40°C and RH of 60 to 90%.

F1		F2		C1		C2	
Time (d)	Co_2 (PPM)	Time (d)	Co_2 (PPM)	Time (d)	Co_2 (PPM)	Time (d)	Co_2 (PPM)
40°C, 60%							
14	843.8	34	802.7	67	904.6	14	946.0
67	1117.5	97	981.3	81	1052.9	97	1063.9
143	1019.0	143	858.0	143	874.5	143	1084.4
174	706.7	174	769.6	174	770.7	174	734.9
40°C, 70%							
14	1366.0	34	1257.8	34	1437.9	67	666.6
97	924.4	81	908.2	81	1050.2	97	1101.1
143	971.8	143	877.6	143	903.0	143	1036.6
174	583.6	174	855.6	174	884.6	174	951.9
40°C, 80%							
25	1226.2	25	1289.3	33	1361.5	33	977.7
33	1147.5			53	1298.3	53	1104.5
40°C, 90%							
14	36547.84	14	38853.84	18	39962.1	18	33957.4

* F1- First replication of feed pea

* F2- Second replication of feed pea

* C1- First replication of clean pea

* C2- Second replication of clean pea

APPENDIX C- MICROBIAL TEST RESULT

Table C.1 Fungi isolated from spoiled pea samples.

Storage conditions	Sample number	Material	Growth*	Fungal species isolated
40^{o}C – 90%	F41	Foreign mat.	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds SS**	XX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
40^{o}C – 90%	F33	Foreign mat.	XXX	*Aspergillus* #3
		Seeds	XXX	*Aspergillus* #1
				Aspergillus #3
		Seeds SS**	X	*Aspergillus* #2
40^{o}C – 90%	F38	Foreign mat.	XXX	*Rhizopus* sp.
				Aspergillus #?
				Penicillium #4
		Seeds	XXX	*Aspergillus* #3
		Seeds SS**	0	
40^{o}C – 90%	F35	Foreign mat.	XXX	*Aspergillus* #2
				Aspergillus #3
		Seeds	XXX	*Aspergillus* #2

Table C.1 (contd.)

				Aspergillus #3
		Seeds SS**	X	*Aspergillus* #3
40°C – 90%	F44	Foreign mat.	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds	XXX	*Rhizopus* sp.
				Aspergillus #?
		Seeds SS**	XX	*Aspergillus* #2
				Aspergillus #3
40°C – 90%	F48	Foreign mat.	XXX	*Rhizopus* sp.
				Aspergillus #?
		Seeds	XXX	*Aspergillus* #2
		Seeds SS**	XX	*Aspergillus* #2
40°C – 90%	C34	Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds SS**	XX	*Aspergillus* #2
				Aspergillus #3
40°C – 90%	C35	Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
		Seeds SS**	XX	*Aspergillus* #1
				Aspergillus #2
40°C – 90%	C36	Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds SS**	XX	*Aspergillus* #1

Table C.1 (contd.)

				Aspergillus #2
				Aspergillus #3
40°C – 90%	C47	Seeds	XXX	*Aspergillus* #2
				Aspergillus #3
		Seeds SS**	XX	*Aspergillus* #1
				Aspergillus #2
40°C – 90%	C42	Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
		Seeds SS**	XX	*Aspergillus* #2
				Aspergillus #3
30°C – 90%	F46	Foreign mat.	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
				Penicillium #4
		Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
				Penicillium #4
				Alternaria alternata
		Seeds SS**	XX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
30°C – 90%	F38	Foreign mat.	XXX	*Rhizopus* sp.
				Penicillium #4
				Aspergillus #?
		Seeds	XXX	*Aspergillus* #2

Table C.1 (contd.)

		Seeds SS**	XX	*Aspergillus* #2
				Aspergillus #3
40°C – 80%	F26	Foreign mat.	XXX	*Aspergillus* #2
				Aspergillus #3
				Aspergillus #6
				Bacterium
		Seeds	XXX	*Aspergillus* #2
		Seeds SS**	0	
40°C – 80%	F1?	Foreign mat.	XXX	*Aspergillus* #3
		Seeds	XXX	*Aspergillus* #2
		Seeds SS**	X	*Aspergillus* #2
30°C – 80%	F23	Foreign mat.	XXX	*Rhizopus* sp.
				Aspergillus #?
				Penicillium #?
		Seeds	XXX	*Aspergillus* #2
				Mucor sp.
		Seeds SS**	0	
30°C – 80%	F13	Foreign mat.	XXX	*Alternaria alternata*
				Aspergillus #2
				Aspergillus #3
		Seeds	XXX	*Aspergillus* #2
		Seeds SS**	X	*Aspergillus* #3
30°C – 80%	F26	Foreign mat.	XXX	*Rhizopus* sp.
				Aspergillus #?
				Penicillium #?
		Seeds	XXX	*Aspergillus* #3

Table C.1 (contd.)

		Seeds SS**	0	
20°C – 80%	F55	Foreign mat.	XXX	*Alternaria alternata* *Penicillium* #4
		Seeds	XXX	*Alternaria alternata* *Aspergillus* #2
		Seeds SS**	X	*Aspergillus* #2 Unknown fungus
20°C – 80%	F38	Foreign mat.	XXX	*Alternaria alternata* *Penicillium* #4
		Seeds	XXX	*Aspergillus* #2 *Aspergillus* #6 *Ascochyta pinodes*
		Seeds SS**	X	*Alternaria alternata*
20°C – 80%	F6	Foreign mat.	XXX	*Alternaria alternata* *Penicillium* #4 Unknown fungus Bacterium
		Seeds	XXX	*Alternaria alternata* *Penicillium* #4 *Cladosporium* sp.
		Seeds SS**	0	
20°C – 80%	C55	Seeds	XXX	*Aspergillus* #9
		Seeds SS**	X	*Aspergillus* #9
10°C – 80%	F85	Foreign mat.	XXX	*Aspergillus* #5 *Penicillium* #11

Table C.1 (contd.)

		Seeds	XXX	*Alternaria alternata*
				Penicillium #11
		Seeds SS**	X	*Alternaria alternata*
30°C	C38	Seeds	XXX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
		Seeds SS**	XX	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3
30°C	C37	Seeds	XXX	*Aspergillus* #3
				Penicillium #4
		Seeds SS**	X	*Aspergillus* #1
30°C	C47	Seeds	XXX	*Aspergillus* #5
				Penicillium #4
		Seeds SS**	X	*Aspergillus* #3
30°C	F48	Seeds	XXX	*Aspergillus* #2
				Aspergillus #3
				Penicillium #4
		Seeds SS**	X	*Aspergillus* #1
				Aspergillus #2
				Aspergillus #3

* XXX = abundant growth from all pieces of material plated; XX = moderate growth from most pieces of material plated; X = limited growth from 1-2 pieces of material plated; 0 = no growth from material plated.

** SS= surface sterilized before plating

APPENDIX D – STATISTICAL ANALYSIS

D.1 Sample SAS Input and Output

D.1.1 Sample SAS input

```
Title ‘Moisture Adsorption of feed pea at 10 and 90%, SINGLE TERM';
Option ls=85;
 Data Lowq;
 input t 1-3 m;
 Cards;
   1 10.62%
   8 18.00%
  15 20.80%
  22 23.21%
  29 25.07%
  36 26.37%
  43 27.60%
  50 28.51%
  57 29.20%
  64 29.64%
  71 30.32%
  78 31.68%
  85 32.41%
  92 33.13%
  99 33.64%
106 34.12%
   1 10.62%
   8 14.19%
  15 16.63%
  22 18.82%
  29 20.88%
```

```
 36 22.12%
 43 23.13%
 50 23.93%
 57 25.27%
 64 26.06%
 71 26.82%
 78 27.86%
 85 29.23%
 92 30.13%
 99 30.90%
106 31.39%
proc nlin best=10 convergence=0.000001 method=marquardt;
 parameter me=10 to 30 by 0.1 k=0.00001 to 0.01 by 0.0001;
 e=exp(-k*(t));
 model m=me+(10.62%-me)*e;
 der.k=-(10.62%-me)*e*t;
 der.me=1-e;
 output out=lgt predicted=py residual=ry;
 proc plot;
 plot m*t='*' py*t='.'/overlay;
 plot ry*t='*';
proc print;
```

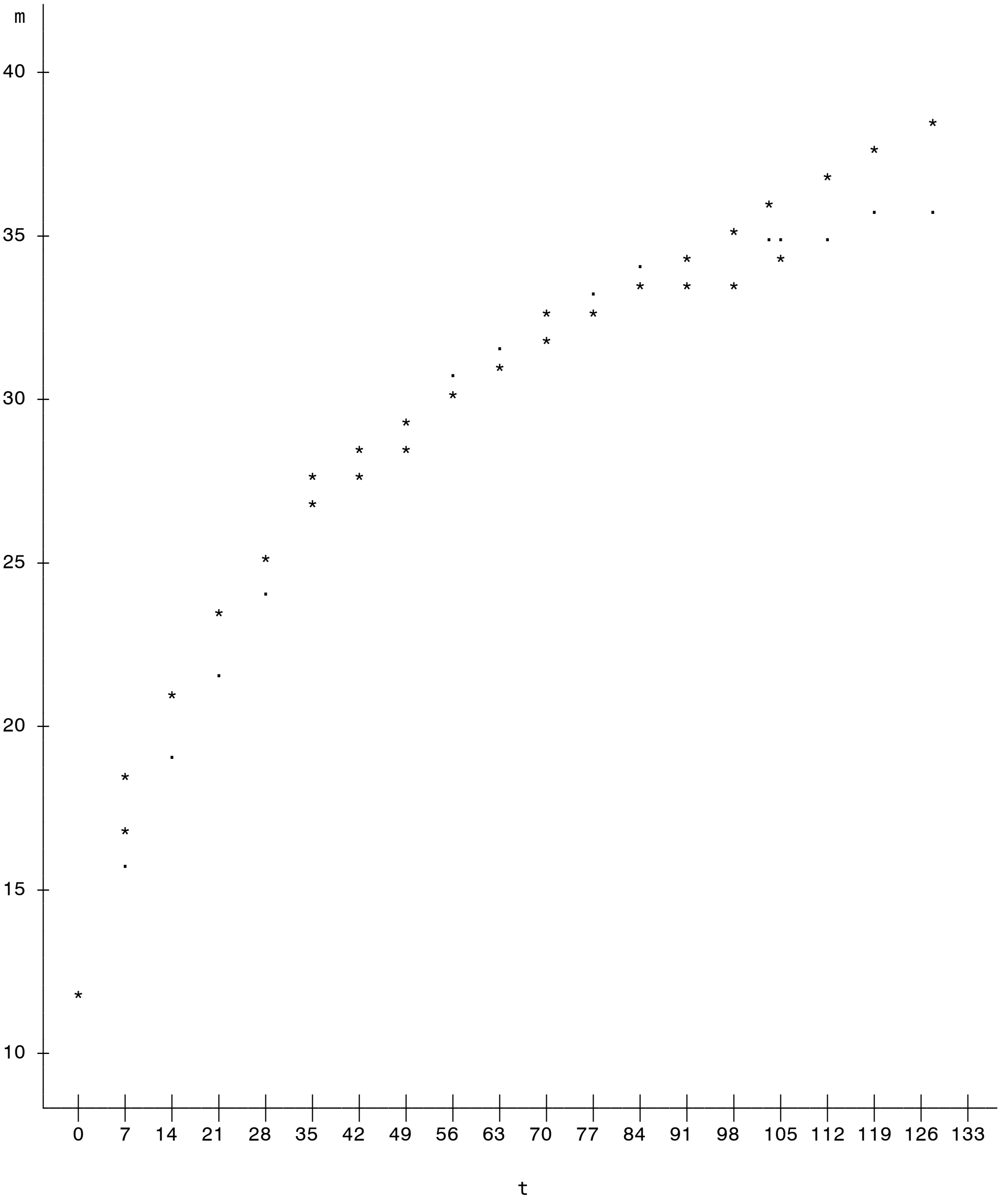
D.1.2 Sample SAS output

```
             Grid Search
                                                    Sum of
                             me            k      Squares

                        35.0000      0.00991       2159.0
                        34.9000      0.00991       2182.8
                        35.0000      0.00981       2196.7
                        34.8000      0.00991       2206.7
                        34.9000      0.00981       2220.5
                        34.7000      0.00991       2230.7
                        35.0000      0.00971       2235.0
```

```
                     34.8000     0.00981      2244.5
                     34.6000     0.00991      2254.9
                     34.9000     0.00971      2258.9

   Moisture Adsorption of whole yellow pea at 10 and 90%,SINGLE TERM        2
                                                15:17 Tuesday, December 7, 2004

                           The NLIN Procedure
                          Dependent Variable m
                            Method: Marquardt

                             Iterative Phase
                                                   Sum of
                 Iter          me           k     Squares

                    0     35.0000     0.00991      2159.0
                    1     26.9193      0.0261      1765.4
                    2     36.5617      0.0260     42.6914
                    3     36.5827      0.0260     42.6867
                    4     36.5835      0.0260     42.6867
                    5     36.5836      0.0260     42.6867
                    6     36.5836      0.0260     42.6867


    NOTE: Convergence criterion met.


                           Estimation Summary

                   Method                   Marquardt
                   Iterations                       6
                   Subiterations                    6
                   Average Subiterations            1
                   R                         8.717E-7
                   PPC(k)                    3.192E-7
                   RPC(k)                    2.131E-6
                   Object                    3.89E-11
                   Objective                  42.6867
                   Observations Read               35
                   Observations Used               35
                   Observations Missing             0


          NOTE: An intercept was not specified for this model.

                                  Sum of        Mean               Approx
Source                    DF     Squares      Square    F Value    Pr > F

Regression                 2     29979.2     14989.6    11588.1    <.0001
Residual                  33     42.6867      1.2935
Uncorrected Total         35     30021.9

Corrected Total           34      1610.8
```

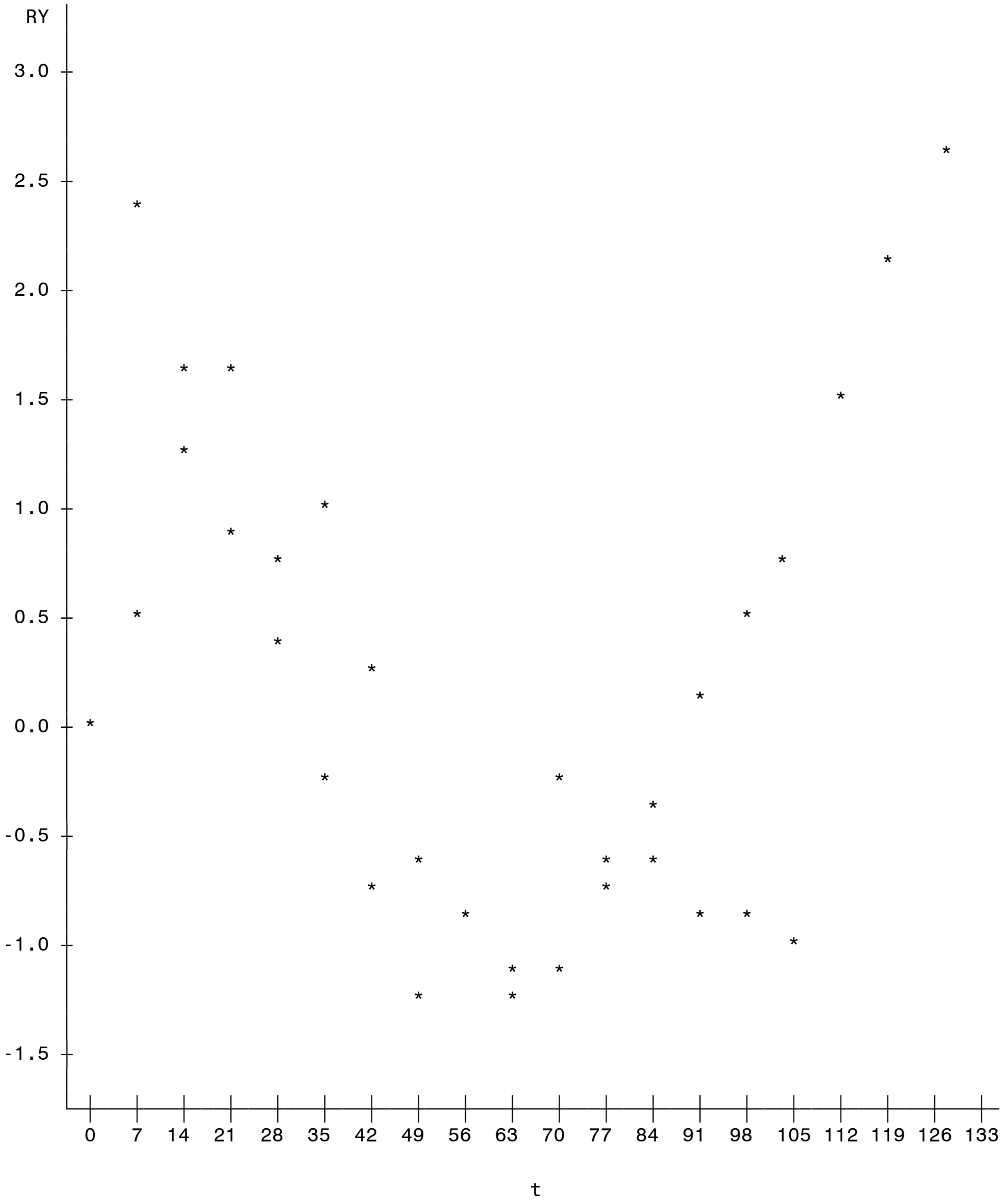
```
                        The NLIN Procedure

                                 Approx
   Parameter      Estimate    Std Error    Approximate 95% Confidence Limits

   me              36.5836       0.5966     35.3698     37.7974
   k                0.0260      0.00166      0.0226      0.0294


                  Approximate Correlation Matrix
                                me                k

                me       1.0000000      -0.8966283
                k       -0.8966283       1.0000000
```

```
Moisture Adsorption of whole yellow pea at 10 and 90%,SINGLE TERM         4
                                         15:17 Tuesday, December 7, 2004

                    Plot of m*t.   Symbol used is '*'.
                    Plot of PY*t.  Symbol used is '.'.
```



```
NOTE: 30 obs hidden.
```

```
          Moisture Adsorption of whole yellow pea at 10 and 90%,SINGLE TERM         5
                                                     15:17 Tuesday, December 7, 2004

                           Plot of RY*t.  Symbol used is '*'.
```



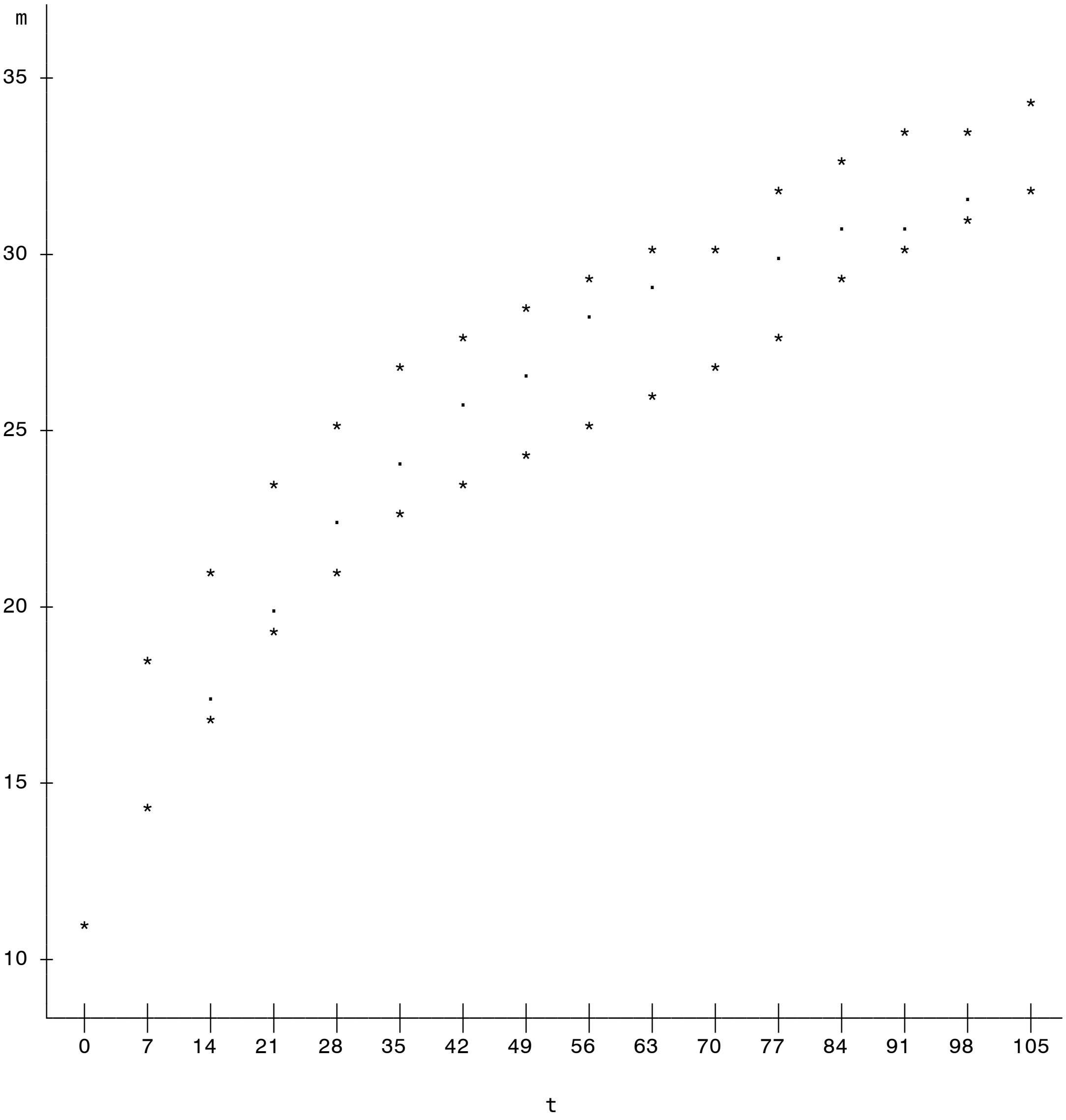
```
NOTE: 2 obs hidden.
```

```
Moisture Adsorption of feed pea at 10 and 90%,SINGLE TERM          12
                                           15:17 Tuesday, December 7, 2004

                    Obs      t      m         PY         RY

                      1      0    10.62    10.6200     0.00000
                      2      7    18.00    14.4539     3.54613
                      3     14    20.80    17.6325     3.16750
                      4     21    23.21    20.2679     2.94212
                      5     28    25.07    22.4529     2.61714
                      6     35    26.37    24.2644     2.10559
                      7     42    27.60    25.7664     1.83365
                      8     49    28.51    27.0116     1.49839
                      9     56    29.20    28.0440     1.15597
                     10     63    29.64    28.9000     0.73999
                     11     70    30.32    29.6097     0.71030
                     12     77    31.68    30.1981     1.48190
                     13     84    32.41    30.6859     1.72407
                     14     91    33.13    31.0904     2.03961
                     15     98    33.64    31.4257     2.21427
                     16    105    34.12    31.7038     2.41625
                     17      0    10.62    10.6200     0.00000
                     18      7    14.19    14.4539    -0.26387
                     19     14    16.63    17.6325    -1.00250
                     20     21    18.82    20.2679    -1.44788
                     21     28    20.88    22.4529    -1.57286
                     22     35    22.12    24.2644    -2.14441
                     23     42    23.13    25.7664    -2.63635
                     24     49    23.93    27.0116    -3.08161
                     25     56    25.27    28.0440    -2.77403
                     26     63    26.06    28.9000    -2.84001
                     27     70    26.82    29.6097    -2.78970
                     28     77    27.86    30.1981    -2.33810
                     29     84    29.23    30.6859    -1.45593
                     30     91    30.13    31.0904    -0.96039
                     31     98    30.90    31.4257    -0.52573
                     32    105    31.39    31.7038    -0.31375
```

```
   Moisture Adsorption of feed pea at 10 and 90%,SINGLE TERM          13
                                            15:17 Tuesday, December 7, 2004

                       The NLIN Procedure
                      Dependent Variable m

                           Grid Search
                                          Sum of
                      me           k     Squares

                 35.0000     0.00991      1204.2
                 34.9000     0.00991      1219.2
                 35.0000     0.00981      1230.0
                 34.8000     0.00991      1234.3
                 34.9000     0.00981      1245.1
                 34.7000     0.00991      1249.5
                 35.0000     0.00971      1256.4
                 34.8000     0.00981      1260.2
                 34.6000     0.00991      1264.8
                 34.9000     0.00971      1271.5

   Moisture Adsorption of feed pea at 10 and 90%,SINGLE TERM          14
                                            15:17 Tuesday, December 7, 2004

                       The NLIN Procedure
                      Dependent Variable m
                        Method: Marquardt

                         Iterative Phase
                                               Sum of
             Iter          me           k     Squares

                0     35.0000     0.00991      1204.2
                1     35.4454      0.0175       204.0
                2     32.2001      0.0250       162.1
                3     33.0943      0.0266       129.7
                4     33.0583      0.0268       129.7
                5     33.0533      0.0268       129.7
                6     33.0526      0.0268       129.7
                7     33.0525      0.0268       129.7
                8     33.0525      0.0268       129.7


NOTE: Convergence criterion met.
```

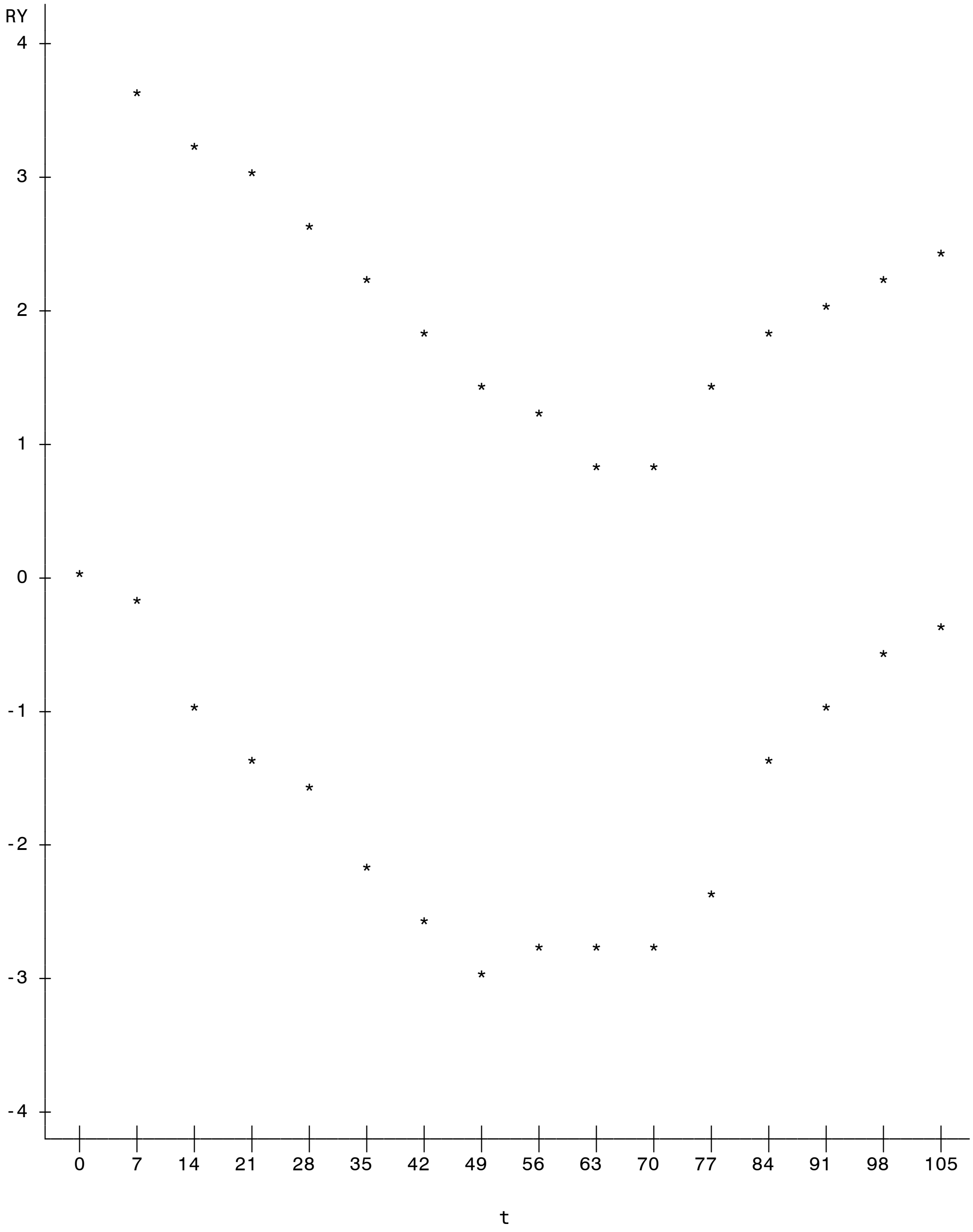
```
                              Estimation Summary

                   Method                   Marquardt
                   Iterations                       8
                   Subiterations                    7
                   Average Subiterations        0.875
                   R                         2.253E-7
                   PPC(k)                    1.785E-7
                   RPC(k)                    1.391E-6
                   Object                    3.48E-12
                   Objective                 129.7296
                   Observations Read               32
                   Observations Used               32
                   Observations Missing             0


          NOTE: An intercept was not specified for this model.

                                  Sum of        Mean               Approx
Source                    DF     Squares      Square    F Value    Pr > F

Regression                 2     21768.1     10884.1    2516.94    <.0001
Residual                  30       129.7      4.3243
Uncorrected Total         32     21897.9

Corrected Total           31      1278.1

       Moisture Adsorption of feed pea at 10 and 90%,SINGLE TERM            15
                                                15:17 Tuesday, December 7, 2004

                           The NLIN Procedure

                                    Approx
      Parameter      Estimate    Std Error    Approximate 95% Confidence Limits

      me              33.0525       1.2711     30.4566     35.6484
      k                0.0268      0.00387      0.0189      0.0347


                     Approximate Correlation Matrix
                                   me               k

                   me       1.0000000      -0.9133503
                   k       -0.9133503       1.0000000
```

```
           Moisture Adsorption of feed pea at 10 and 90%,SINGLE TERM           16
                                            15:17 Tuesday, December 7, 2004

                    Plot of m*t.   Symbol used is '*'.
                    Plot of PY*t.  Symbol used is '.'.
```



```
NOTE: 21 obs hidden.
```

Plot of RY*t. Symbol used is '*'.



NOTE: 1 obs hidden.

```
Moisture Adsorption of feed pea at 10 and 80%,SINGLE TERM           18
                                           15:17 Tuesday, December 7, 2004

            Obs      t       m          PY          RY

              1      0     10.62     10.6200     0.00000
              2      7     18.00     14.4539     3.54613
              3     14     20.80     17.6325     3.16750
              4     21     23.21     20.2679     2.94212
              5     28     25.07     22.4529     2.61714
              6     35     26.37     24.2644     2.10559
              7     42     27.60     25.7664     1.83365
              8     49     28.51     27.0116     1.49839
              9     56     29.20     28.0440     1.15597
             10     63     29.64     28.9000     0.73999
             11     70     30.32     29.6097     0.71030
             12     77     31.68     30.1981     1.48190
             13     84     32.41     30.6859     1.72407
             14     91     33.13     31.0904     2.03961
             15     98     33.64     31.4257     2.21427
             16    105     34.12     31.7038     2.41625
             17      0     10.62     10.6200     0.00000
             18      7     14.19     14.4539    -0.26387
             19     14     16.63     17.6325    -1.00250
             20     21     18.82     20.2679    -1.44788
             21     28     20.88     22.4529    -1.57286
             22     35     22.12     24.2644    -2.14441
             23     42     23.13     25.7664    -2.63635
             24     49     23.93     27.0116    -3.08161
             25     56     25.27     28.0440    -2.77403
             26     63     26.06     28.9000    -2.84001
             27     70     26.82     29.6097    -2.78970
             28     77     27.86     30.1981    -2.33810
             29     84     29.23     30.6859    -1.45593
             30     91     30.13     31.0904    -0.96039
             31     98     30.90     31.4257    -0.52573
             32    105     31.39     31.7038    -0.31375
```

D.2 Sample ANOVA Tables and Residual Plots

D.2.1 ANOVA Table and Residual Plot in Dynamic Environment

Table D.1 Summary output for clean pea for k as a function of temperature and relative humidity

Regression Statistics	
Multiple R	0.90656674
R Square	0.82186325
Adjusted R Square	0.8091392
Standard Error	0.00035159
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7.98448E-06	8E-06	64.591	1.29803E-06
Residual	14	1.73062E-06	1.2E-07		
Total	15	9.7151E-06			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	3.1202E-06	0.000142038	0.02197	0.9828	-0.00030152	0.00030776	-0.0003015	0.000307761
K_c-calculated	0.99649948	0.123990965	8.03687	1E-06	0.730565071	1.26243389	0.73056507	1.262433887

Table D.2 Summary output for feed pea for k as a function of temperature and relative humidity

Regression Statistics	
Multiple R	0.8771201
R Square	0.76933968
Adjusted R Square	0.75286394
Standard Error	0.00017459
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.42328E-06	1.4E-06	46.695	8.14796E-06
Residual	14	4.26722E-07	3E-08		
Total	15	1.85E-06			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.565E-06	0.000119172	0.02152	0.9831	-0.00025303	0.00025816	-0.00025303	0.000258164
Kf-calculated	0.99656936	0.145838065	6.8334	8E-06	0.683777538	1.30936117	0.683777538	1.309361174

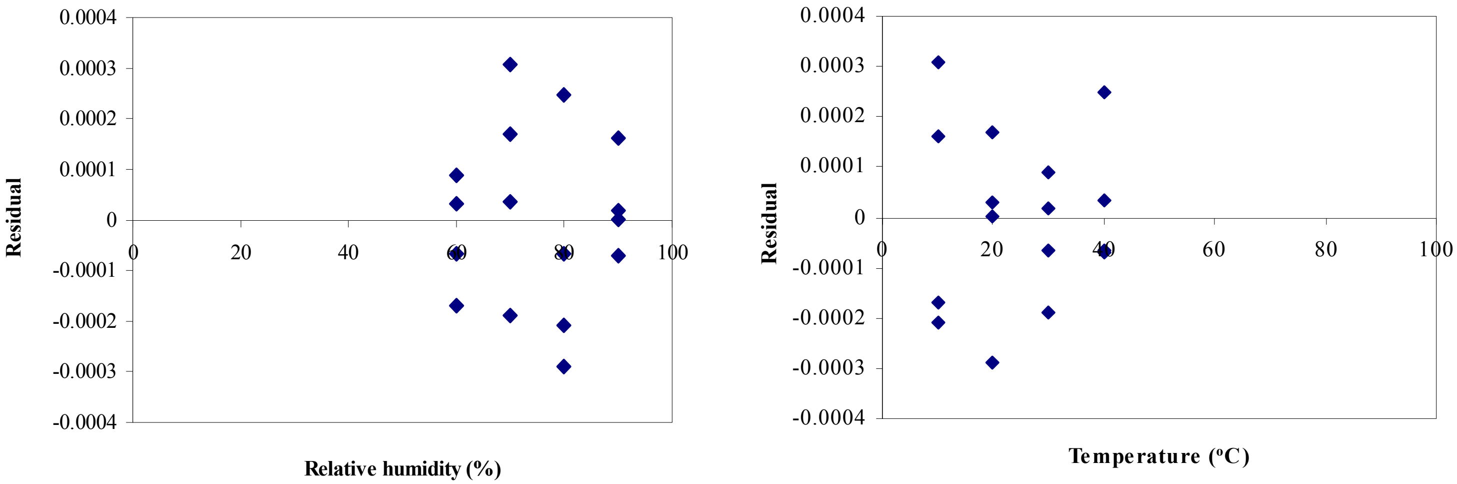


Figure D.1 Plot of residual vs. relative humidity and temperature for feed pea.

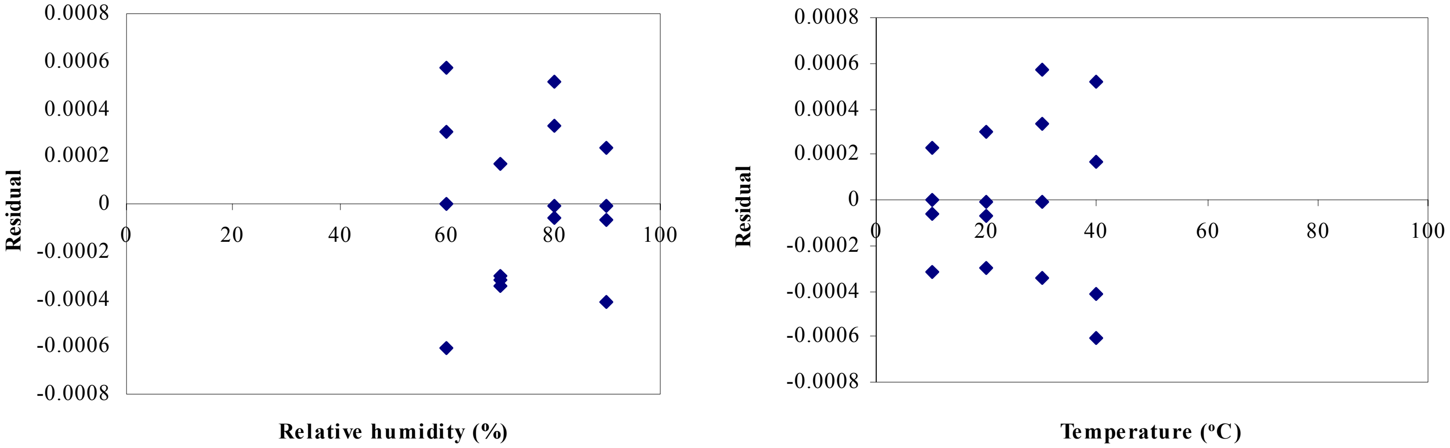


Figure D.2 Plot of residual vs. relative humidity and temperature for clean pea.

D.2.1 Sample ANOVA Table and Residual Plots in Static Environment

Table D.3 Summary output for clean pea for k as a function of temperature and relative humidity

Regression Statistics	
Multiple R	0.95601023
R Square	0.91395556
Adjusted R Square	0.90780953
Standard Error	0.01999873
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.059475083	0.05948	148.707	7.60678E-09
Residual	14	0.005599288	0.0004		
Total	15	0.06507437			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.00213459	0.008770847	0.24337	0.81125	-0.016677024	0.0209462	-0.01667702	0.0209462
K-calc	0.97617902	0.080050548	12.1945	7.6E-09	0.80448752	1.14787053	0.80448752	1.14787053

Table D.4 Summary output for feed pea for k as a function of temperature and relative humidity

Regression Statistics	
Multiple R	0.896070659
R Square	0.802942625
Adjusted R Square	0.788867098
Standard Error	0.026704673
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.040681259	0.040681	57.0453	2.65755E-06
Residual	14	0.009983954	0.000713		
Total	15	0.050665212			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.002474582	0.01422667	0.17394	0.864403	-0.028038617	0.032987781	-0.028038617	0.032987781
K-calc	0.974591667	0.129036557	7.552834	2.66E-06	0.697835532	1.251347802	0.697835532	1.251347802

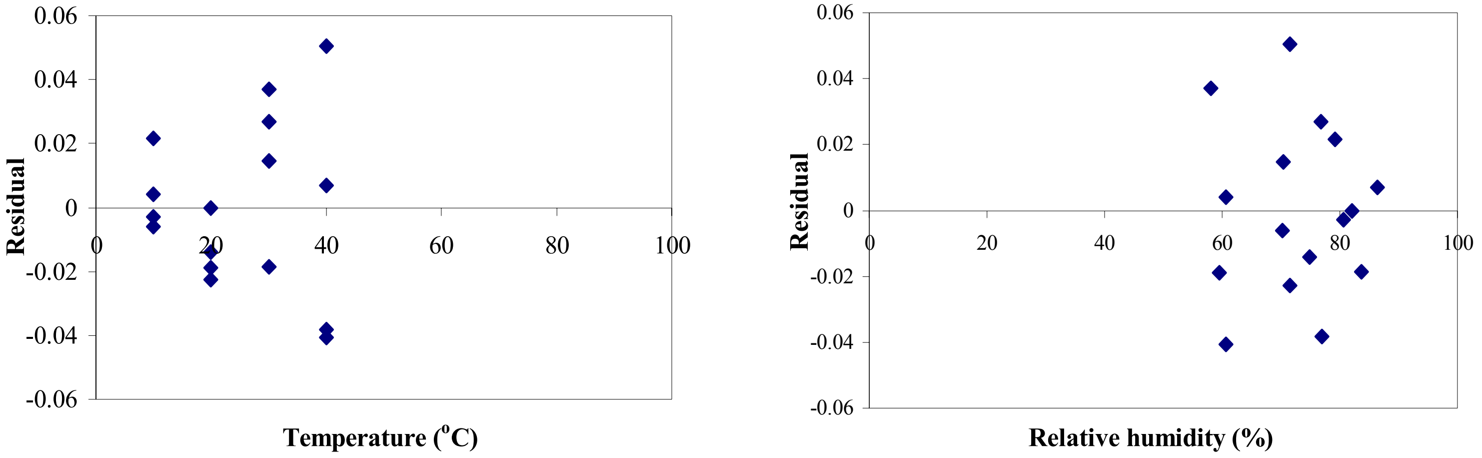


Figure D.3 Plot of residual vs. temperature and relative humidity for feed pea.

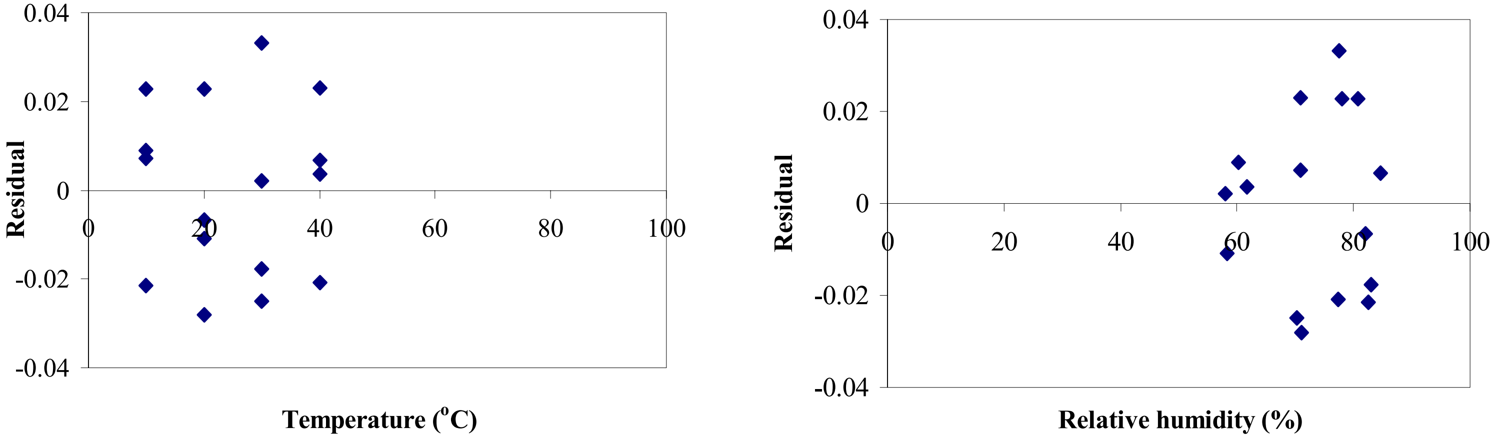


Figure D.4 Plot of residual vs. temperature and relative humidity for clean pea.

APPENDIX E – APPEARANCE OF PEAS AT THE END OF STORAGE PERIOD

Figure E.1 Clean and feed pea appearance after 163 days of storage at 10°C and 60%RH.

Figure E.2 Feed and Clean pea appearance after 212 days of storage at 10°C and 70%RH.

Figure E.3 Appearance of clean pea after 104 and 119 days of storage at 10°C and 90 and 80% RH respectively.

Figure E.4 Appearance of clean and feed peas after 216 days of storage at 20°C and 60% RH.

Figure E.5 Appearance of clean and feed peas after 216 days of storage at 20°C and 70% RH.

90% RH respectively.

Figure E.6 Appearance of clean and feed peas after 42 and 35 days of storage at 20°C and 90% RH respectively.

RH.

Figure E.7 Appearance of clean and feed peas after 162 days of storage at 30°C and 60% RH.

Figure E.8 Appearance of feed and clean peas after 156 days of storage at 30°C and 70% RH.

Figure E.9 Appearance of feed and clean peas after 174 days of storage at 40°C and 60% RH.

Figure E.10 Appearance of feed and clean peas after 174 days of storage at 40°C and 70% RH.

Figure E.11 Appearance of feed and clean peas after 34 days of storage at 40°C and RH of 80% and 90% respectively.

Figure E.12 Appearance of whole green and split yellow and green peas after 15 and 9 days of storage at 40°C and 90%RH respectively.

Figure E.13 Photographs of cracked seed coat and shriveled peas after 15 days of storage at 40°C and 90%RH.

Figure E.14 Photographs of other damaged pea and small pea after 6 and 15 days of storage at 40°C and 90% RH respectively.

Figure E.15 Photographs of foreign materials after 9 days of storage at 40°C and 90%.