Spoilage characteristics of field pea under adverse storage conditions

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Dadgar, S., Tabil, L.G., Crerar, W.J. and Morrall, R.A.A. 2009. **Spoilage characteristics of field pea under adverse storage conditions**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada. **51**: 1.xx–1.xx Field pea is the most produced and exported pulse crop in Canada. Canadian field pea exported to countries with tropical climates is at particular risk due to rapid deterioration. It is therefore important to develop practical strategies for safe storage of field pea, which is most often exported as animal feed. This study was conducted to examine the conditions that lead to mold growth during the storage and transport of field pea. Tropical and subtropical conditions were simulated in airtight chambers. Relative humidities (RH) of 60, 70, 80, and 90% and temperatures of 10, 20, 30, and 40°C were used. Both whole sound pea and feed-grade pea were observed for changes in moisture content (MC) and mold appearance at different time intervals. Concentration of carbon dioxide (CO_2) produced during storage was measured in airtight chambers to control the condition existing in sealed containers. Molds were identified after their appearance on the samples. Mold-free days for both feed-grade pea and whole sound pea were modeled at temperatures of 10, 20, 30, and 40°C and RH of 80 and 90%. It was found that if the temperature and RH exceeded 20°C, and 80%, respectively, the shelf-life of both whole sound pea and feed-grade pea was shortened to 35 and 40 days, respectively. Whole sound pea was contaminated by storage fungi, whereas feed-grade pea was contaminated by both storage and field fungi. **Keywords:** field pea, feed-grade pea, relative humidity, temperature, fungi, mold, spoilage index.

Au Canada, le pois fourrager est la légumineuse la plus produite et exportée. Les pois fourragers canadiens qui sont exportés dans des pays tropicaux présentent des risques particuliers de détérioration rapide. Il est par conséquent important de développer des stratégies pratiques pour le stockage sécuritaire des pois fourragers qui sont généralement exportés pour l'alimentation animale. Cette étude a été réalisée pour examiner les conditions qui provoquent la croissance de moisissures durant le stockage et le transport des pois fourragers. Les conditions tropicales et subtropicales ont été simulées dans des chambres étanches. Des valeurs d'humidité relative (HR) de 60, 70, 80 et 90% et des températures de 10, 20, 30 et 40°C ont été utilisées. Des pois entiers intacts ainsi que des pois de qualité inférieure destinés à l'alimentation animale (AA) ont été observés pour évaluer les changements en teneur en eau (TE) et l'apparition de moisissures à différents intervalles dans le temps. La concentration de dioxyde de carbone (CO_2) produit durant le stockage était mesurée dans les chambres étanches pour contrôler les conditions présentes dans les contenants scellés. Les moisissures étaient identifiées après leur apparition sur les échantillons. Les jours sans moisissure pour les pois AA et les pois entiers intacts ont été modélisés à des températures de 10, 20, 30 et 40°C et des HR de 80 et 90%. Il a été démontré que si la température et HR excédaient 20°C et 80%, respectivement, la durée utile des pois entiers intacts et des pois AA était réduite à 35 et 40 jours, respectivement. Les pois entiers étaient contaminés par des fungis de stockage tandis que les pois AA étaient contaminés tant par des fungis de stockage et des fungis de champs. **Mots clés:** pois fourrager, pois destinés à l'alimentation animale, humidité relative, température, fungi, moisissure, index de dommage.

INTRODUCTION

Field pea (*Pisum sativum* L.) is an annual cool-season legume crop that is grown on over 10 million hectares worldwide. Field pea or "dry pea" is marketed as a dry, shelled product for either human food or animal feed (Anonymous 2003), containing 1.4–2.8% fat in different cultivars (Welch and Griffiths 2006). The fatty acid composition of peas is 12.0–16.6% palmitic, 2.5–4.2% stearic, 14.2–33.3% oleic, 43.7–60.9% linoleic, and 6.4–13.4% linolenic. Over 90% of the oil content is in the cotyledons (Welch and Griffiths 2006). Since the mid-1980s, Saskatchewan has produced the majority of Canadian field pea (70%) with significant acreage in Alberta (25%) and Manitoba (Agriculture and Agri-Food Canada 2004).

According to the Canadian Grain Commission (2003), there are three major grades of field pea based on damaged pea and pea of other colors, including No.1, No. 2, and No. 3 Canada. The maximum allowable limit of foreign materials (FM) for yellow field pea used for human consumption is 0.05% for all grades. Feed-grade pea is classified as a mixture of green and yellow peas with various specifications on moisture, foreign material (FM), and percentage of pulses other than green and yellow peas in the export market. Mixtures of pea falling below No. 3 Canada are classified as feed-grade pea. The maximum allowable level of FM is 6% for feed-grade pea. The quality of feed-grade pea is affected significantly by FM level and composition. At a given storage temperature and relative humidity (RH), FM may adsorb moisture differently from the pea. FM increases the susceptibility of feed-grade pea to microbial development and quality deterioration due to: (a) higher moisture adsorption capability than the grain particles; and (b) their size, and blocking of airflow during storage (Booth et al. 2001).

Moisture and temperature are the most important factors in storage of grains and grain products as they influence the rate of deterioration during storage. Most rapid deterioration occurs under conditions of high temperature and moisture. 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 (Anderson and Alcock 1954; Christensen 1982; Bala 1997; Kosolofski et al. 1998). Bennett-Lartey (1991) showed that RH, temperature, O_2, and CO_2 content were the most important factors affecting the viability of stored pea, sunflower, and groundnut seeds. RH affects seed quality by influencing the seed MC and the growth and reproduction of fungi and insects.

Fungi invading peas are categorized as field fungi or storage fungi. Field fungi invade the seeds while the plant is still growing in the field, whereas, with a few exceptions, storage fungi develop only after the product is in storage. The damage caused by field fungi is done before harvest and does not continue to increase during storage (Sauer 1992).

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 high MC grains stored at low temperatures. A variety of other fungi including *Rhizopus*, *Mucor*, and *Nigrospora* might grow in high-moisture grain during storage (Justice and Bass 1978; Christensen 1982; Brooker et al. 1992; Bala 1997; and Sauer 1992). *Aspergillus*, *Penicillium*, *Rhizopus*, *Mucor*, and *Nigrospora* are mainly storage fungi, whereas, *Alternaria alternata*, *Fusarium equiseti*, *Cladosporium* spp. and *Ascochyta pinodes* are field fungi (Sauer 1992).

There is usually minimal concern for feed-grade pea storage in Canada with its cool temperate climate, but as this commodity is exported to tropical countries (about 60% of the total exported pea), 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. 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.

The main objective of this research project was to determine safe storage conditions for Canadian produced and exported field pea when stored under high humidity and temperature conditions. The specific objectives were:

(a) to determine the number of mold-free days for clean pea and typical feed-grade pea subjected to the aforementioned storage conditions;
(b) to identify genus of fungi; and
(c) to model mold development under adverse storage conditions.

MATERIALS and METHODS

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. Quality factors such as smoothness, roundness, and an intact seed coat were used to sort pea. Only good quality whole pea was used in this experiment. This is referred to in the experiment as "clean pea".

The sample of feed-grade 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 refers to any damage other than splits, insect damage, heating or shrivelling. In other words, 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.

Experimental plan

The variability in the composition and quality of feed-grade 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 and typical feed-grade pea to eliminate as many variables as possible that impact mold development. The results from No. 1 Canada were used as a standard against the other sample. These data were then used to determine the effect of temperature and RH on both MC and mold growth.

In this study, both clean and feed-grade peas were stored in duplicate at temperatures of 10, 20, 30, and 40°C and RH of 60, 70, 80, and 90% in airtight chambers (Fig. 1). The experimental plan for this study is shown in Table 1.

Experimental approach

Forty-eight airtight cylindrical chambers were designed and built to provide a controlled environment for pea storage (Fig. 1). They were made of PVC pipe, with clear acrylic end plates and two shelves to hold the Petri dishes. 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 in the top and six small holes drilled around the outer edge to allow air to circulate easily throughout the container. The top support tray was made of acrylic or Plexiglas® in order to increase visibility

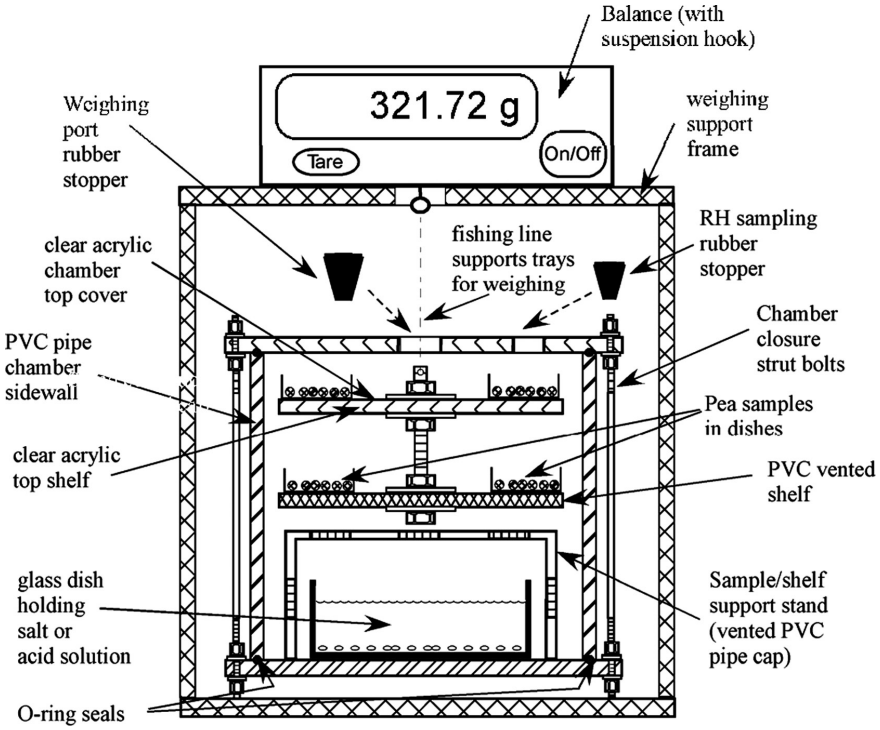

Fig. 1. Schematic diagram of weighing the samples inside the airtight chamber, with the trays suspended on fishing line hooked under the balance.

through to the second shelf of samples. The top of the support trays had fishing line tied to it, as well as a fishing leader. Eight 60 mm×15 mm plastic Petri dishes were placed on the shelves in each airtight chamber. Rubber stoppers were used to cover the access holes on the top of the acrylic plate in order to provide airtight condition inside the chamber.

Four controlled environment cabinets (Conviron Plant Growth Chamber PGR15, Controlled Environment Ltd., Winnipeg, MB) at the Phytotron facilities in 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 and RH stabilization, samples were placed in the chambers. Desired RH was provided and maintained by placing a glass dish containing 200 mL of saturated salt solution or dilute sulphuric acid solution at the bottom of each test chamber. The solutions controlling the humidity (shown in Table 2) were checked weekly. 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.

Table 1. Experimental plan for storage and moisture adsorption study in static environment.

Variable	Level	Number
Type of pea	Clean, feed-grade	2
Temperature (°C)	10, 20, 30, 40	4
Relative humidity (%)	60, 70, 80, 90%	4
No. of treatments		32
No. of replicates		2
No. of runs/experiment		64

Mass of the samples was recorded once a week in order to determine their MC. This was done by removing the middle rubber stopper at the top of the lid and running the fishing leader to a hook at the bottom of a scale (Mettler PL1200, Mettler Instrumental, CH-8606, Greifensee, Zurich, Switzerland) (Fig. 1). Mass was measured this way to minimize the disruption of the samples and environmental condition inside the container.

Measurement of CO_2 inside the chamber

The CO_2 content inside the airtight chambers was tested every 2 to 3 weeks, as it was considered that if the containers were completely sealed to the outside environment, there might be a build up of CO_2 concentration that could result in mold growth retardation or inhibition on the samples. Air samples, taken from the containers by a syringe, were analyzed for CO_2 using a Varian Micro-GC CP-2003 gas chromatograph (Varian Inc., Palo Alto, CA).

Moisture content measurement

The initial MC of the whole pea and 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 mass of the samples

Table 2. Saturated salt and dilute sulfuric acid solutions used in the experiments (Rahman 1995; Bala 1997; 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%)

and its initial MC, and it was also determined by AACC standard 44-15A methods.

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. 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.

Data analysis and Processing

Data were imported to a Microsoft Excel (Microsoft Corp., Redmond, WA) worksheet. 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 similarly suggested by Khoshtaghaza et al. (1999) to estimate the number of days until the development of visible mold growth in alfalfa cubes:

$$Y = e^{(a - b\ T - c\ RH)} \tag{1}$$

Where Y is storage time (d), T is temperature (°C), RH is relative humidity (decimal), and a, b, and c are constants. Equation 1 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 calculated (Khoshtaghaza et al. 1999):

$$SI = \sum_{i=1}^{n} \left(\frac{\Delta t}{Y} \right)_i \tag{2}$$

Where Y is the storage time (d) to molding calculated from Eq. 1 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 indicates that samples in the container

Table 3. Type of fungi observed on both feed-grade pea and clean pea after spoilage.

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

were moldy. SI in this study is calculated only as a demonstration of how it can be used to determine the onset of mold development for pea samples during storage and transport.

RESULTS and DISCUSSION

Fungi appearance and identification

The majority of fungi isolated were species of *Aspergillus* and *Penicillium*. Fungi were not identified to the species level in this experiment because it is 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 species. In some cases, 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 that it was not even possible to classify *Aspergillus* and *Penicillium* into putative species. 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*). Mills and Woods (1994) showed that *Penicillium* and *Eurotium* species were the most important storage fungi associated with quality deterioration of pea and bean. However, *A. flavus* Link and *Rhizopus arrhizus* Fischer were also identified. In pea, *A. candidus* Link ex Fr. and to a lesser extent *A. ochraceus* Wilhelm and *A. wentii* Wehmer additionally occurred, which were not identified in the current study. The pre-harvest fungi *Cladosporium cladosporioides* (Fres.) de Vries and *Alternaria alternata* Keissler and bacteria occurred on both pea and bean (Mills and Woods 1994).

Table 4. Relative humidity inside the storage chambers and number of mold-free days for whole sound pea.

	Relative humidity (%)			
Temperature (°C)	Mean	Standard dev.	Mold-free days	MC at mold onset (% w.b.) termination of storage
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.

In the current study, seeds that had been stored at higher temperatures and RH levels were molded mainly by storage fungi. Table 3 summarizes the fungi observed at each temperature and RH. Only species of *Aspergillus* and *Penicillium* that are storage fungi were identified on clean pea, and no field fungi were observed on clean pea at any of the temperatures tested. In the study conducted by Dadgar (2005) on the effect of feed pea components on molding at storage temperature of 40°C and RH of 90%, it was revealed that other damaged pea followed by FM and split pea were the first components that become moldy after 6, 9, and 9 days of storage, respectively. The study by Dadgar (2005) on storage of feed-grade pea also reported that other damaged pea and FM were the first components that became moldy inside the Petri dishes at any storage condition.

CO_2 concentration was determined to be higher in contaminated chambers, which were exposed to RH of 80 and 90%, and at all the temperatures tested, indicating mold respiration in these containers. However, the amount of CO_2 (ppm) was close to the ambient CO_2 concentration in the chambers that were exposed to humidities of 60 and 70% at all the temperatures tested, indicating no fungal growth at lower RH. Furthermore, the concentration of CO_2 inside the container at temperature of 10°C and 80% RH seemed to be similar to the ambient air. The CO_2 concentration inside other samples varied within the range of normal CO_2 variation in air.

Mold-free days

The number of mold-free days, along with mean RH and percentage MC at mold onset are shown in Tables 4 and 5 for whole sound pea and feed-grade pea, respectively. Molds were observed 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 appearance occurred above 14% MC at high temperature (40°C, 80% RH) and above 14.8% at lower

Table 5. Relative humidity of storage chambers and number of mold-free days for feed-grade pea.

	Relative humidity (%)			
Temperature (°C)	Mean	Standard dev.	Mold-free days	MC at mold onset (% w.b.) termination of storage
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.

storage temperature (20°C, 80% RH). Therefore, as was also shown by Vertucci et al. (1994), the acceptable MC for seed storage increased as temperature decreased. As fungi favor elevated temperature and RH, safe storage at higher temperature and higher RH was shorter in duration. ASAE D535 MAY 2005 (ASABE 2006) shows that storage time of shelled corn at 16% MC (wet basis) has been shown to decrease from 339 days to only 11 days when the temperature increased from 10 to 40.6°C. While the safe storage time of shelled corn would decrease to only 26 days if the MC increased from 16 to 24% (wet basis) assuming they are both exposed to storage temperature of 10°C (ASABE 2006). The results of this study are in agreement with that by Gorecki et al. (1985), in which a marked deterioration was observed in peas stored at 90% RH after 7 months, whereas no effect was observed on seeds stored at 50% RH. Mold was not visually detected on either feed-grade or clean peas at temperatures of 10, 20, 30, and 40°C and RH of 60 and 70% for the duration of the experiment. 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 (vs. the 216 days at 10°C and 70% RH). Storage duration under these conditions would also be at least 216 days or longer. It was difficult to achieve the 60% RH at 10°C; therefore, the salt solution was replaced with different types several times in order to achieve the 60% RH. The reason for this complication cannot be explained at this point. The results of this experiment are in agreement with that of Mills and Woods (1994), who found no deterioration after 147 days of storage for pea initially stored at 22°C and 14.5% MC, as well as that of Booth et al. (2001) who reported that storage conditions at temperatures of 30°C and above, combined with RH of 80% or higher, limited the storage life of whole sound pea to less than 100 mold-free days. This was also true at RH of 85–90% or higher, at all temperatures (10, 20, 30, and 40°C) studied. 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.

Equation 1 was fitted to the number of mold-free days (d) as a function of temperature (°C) and RH (decimal) for both feed-grade and clean peas. For clean pea:

$$Y = e^{(12.35 - 0.055\ T - 8.69\ RH)} \quad (3)$$

with coefficient of determination (R^2) of 0.91 and mean square error (MSE) of 140.73.

For feed-grade pea:

$$Y = e^{(7.10 - 0.05\ T - 2.71\ RH)} \quad (4)$$

with R^2 of 0.81 and MSE of 163.67.

Equations 3 and 4 are valid for a temperature range of 10 to 40°C and a 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 Eq. 3 for clean pea was compared with the number of mold-free days for alfalfa cube at similar 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 protecting the endosperm and has less capacity to adsorb moisture.

The spoilage index (SI) was calculated using Eq. 2. This equation could simply be expressed as:

Table 6. Spoilage index values for clean and feed-grade pea as affected by temperature (10, 20, 30, and 40°C) and relative humidity (RH) (80 and 90%).

Setpoint		Clean pea			Feed-grade pea		
Temperature (°C)	RH (%)	Mean RH (%)	Storage duration (d)	Spoilage index	Mean RH (%)	Storage duration (d)	Spoilage index
10	80	80.9	120	1.01	78.2	64	0.73
10	80	80.6	120	0.99	80.2	71	0.86
10	90	81.0	126	1.07	80.5	105	1.28
10	90	83.9	105	1.15	80.7	105	1.28
20	80	79.4	79	1.01	75.4	56	0.98
20	80	76.6	93	0.94	74.2	63	1.07
20	90	81.4	43	0.66	81.6	35	0.73
20	90	82.5	36	0.61	82.4	35	0.74
30	80	77.7	54	1.04	76.9	34	1.03
30	80	77.2	54	0.99	76.7	34	1.03
30	90	83.1	32	0.98	84.7	25	0.94
30	90	82.8	32	0.96	82.4	25	0.88
40	80	77.5	40	1.31	76.7	34	1.71
40	80	77.2	54	1.72	77.1	27	1.37
40	90	86.3	19	1.34	84.9	14	0.88
40	90	82.9	22	1.15	87.8	14	0.95

$$SI = \frac{Y_{exp}}{Y_{cal}} \quad (5)$$

where Y_{exp} is the experimental storage time at which the samples went molded (d) and Y_{cal} is the calculated storage time from Eq. 3 or 4 (d). The values for spoilage index for both feed-grade and clean pea are presented in Table 6. SI is indicative of pea quality during transport and storage. Good quality pea has a low SI (<1) and spoiled and molded pea has SI ≥ 1.

As Table 6 shows, the probability of pea to become moldy is 1.0 when SI ≥ 1. For example, the probability of clean pea to become moldy after 43 days of storage at 20°C and 81.4% RH is only 0.66, whereas clean pea will surely become moldy (probability = 1.0) after 79 days of storage at 20°C and 79.4% RH. These values are only applicable 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 that all the spoiled and moldy samples would have a SI ≥ 1; however, in some cases in this study when mold appeared on the samples, SI was lower than one. For SI index to be accurate, another storage study has to be conducted for data verification, wherein RH and temperature will be measured at close intervals, i.e., every day or every half a day.

CONCLUSION

The storage stability of peas is similar to that of other agricultural products; they can be safely kept at low temperature and low humidity. This research shows that maintaining temperatures below 20°C and RH in the airtight chambers below 70% extended the storage life of both clean and feed-grade 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-grade 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 clean pea and feed-grade pea.

Fungi that appeared on the pea samples were identified. On clean 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.

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 became molded.

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