Utilization of mechanical compression as a disinfestation technique for Hessian fly (*Mayetiola destructor* (say)) in timothy hay: Field test

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Abstract: Baled timothy hay underwent testing at a hay processing plant in Canada to determine if mechanical compression (rebaling) could be used as a disinfestation protocol for Hessian fly (Mayetiola destructor (Say)) puparia. Pressure sensitive films were randomly placed throughout the hay material, on the chamber walls, and in different orientations, to assess the hay compaction unit's ability to induce the required pressure to crash a Hessian fly puparium in the hay. Attached to the pressure films were organdy cages containing wheat seedlings infested with Hessian fly puparia. The variables which were tested included the hold time (0.5 and 2.0 s), applied pressure (10.34 and 12.41 MPa), and timothy hay quality (low-moisture first cut, high-moisture first cut and high-moisture second cut hay). A total of 36 tests were conducted. For each test, 10 Hessian fly cages and 10 pressure sensitive films were used. Each test cage contained approximately 168.56 Hessian fly puparia, translating into a total Hessian fly count of 60681 for the entire field test. Analysis of the pressure sensitive films showed that 100% of the hay experienced at least 200 kPa (29 psi) of pressure. Following the 75-day post experiment emergence period, 0.0066% of the puparia survived, which may be due to the fact that the emerged puparia might have not been crushed and not subjected to a pressure of at least 20.6 kPa. The applied pressures affected Hessian fly emergence by considerably reducing the number of puparia that emerged. However, Hessian fly emerged from one of the cages in two tests. Most of the Hessian fly puparia were destroyed irrespective of the applied pressure, hold time or hay quality.

Keywords: Hessian fly, disinfestation, hay bale, compression, rebaling, emergence

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1 Introduction

The disinfestation of the Hessian fly (*Mayetiola destructor* (Say)) in hollow stem plants has been an area of interest for researchers for many years. Much of the research focus has been to specifically rid this pest from

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timothy hay (*Phleum pratense*) for the purpose of exporting it to Japan. Timothy is not a host of Hessian fly, however volunteer crops (wheat, barley, rye and other hollow stemmed grasses) growing as weeds in timothy hay fields may be unintentionally cut and baled with the hay. Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF) has strict guidelines for imported forages in order to ensure that Hessian fly does not infest their extensive rice growing industry. If hollow stemmed grasses and cereal plants are detected in the timothy hay during inspection, the shipment is rejected and shipped back to Canada with cost borne by the exporter usually in the form of "ship back insurance".

Hessian fly can have up to two generations in one year, one in early spring and the other, in the fall. The first rain of the season usually triggers their emergence[1]. The larva, which has a reddish color, gradually moves towards the base of the leaf. This is where it will feed and then penetrate the stem of the plant. After the larva reaches full growth, a rigid outer shell (puparium) is formed from the larval skin that covers the pupa, which resembles a "flaxseed." It is at this point that they enter a period of aestivation, where they will emerge the following year and lay more eggs[2]. Buntin and Raymer[3] reported that Hessian fly infestations in soft red winter wheat could reduce the total dry matter yield by 14% to 46%.

Research studies on the disinfestation of Hessian fly in timothy hay have primarily been conducted within North America. Yokoyama and co-workers[4-9] developed a disinfestation protocol involving mechanical compression and fumigation. Compression showed the same level of control in the four corners and middle positions of the front, middle and back section of the bale. Hydrogen phosphide was used in the fumigation process in a multiple quarantine treatment. This method of disinfestation was proven to be 100% effective. However, forage exporters in Canada are hesitant to use chemical fumigation because of the large investment involved and the unfriendliness of the chemical fumigation to the environment.

In Canada, Sokhansanj and co-workers[10] investigated the effectiveness of thermal treatment as a potential disinfestation technique. It was determined that the temperature throughout the entire bale must reach at least 60ºC for at least 3 min. However, uniform heating of the bale was not possible within a reasonable amount of time[11]. Tabil and co-workers[12] carried out further experiments on the possibilities of thermal disinfestation. It was concluded that drying the product should be prevented for a faster uniform baled hay heating. The Canadian Hay Association tested the effectiveness of this research for approval by Japan's MAFF. Thirty thousand Hessian puparia were treated to 60ºC for 3 min, and the treatment did not result in 100% mortality rate[13]. Presently, the accepted quarantine method for Hessian fly puparia control for Canadian timothy hay exports is through visual inspection.

In 1993, Yokoyama and co-workers[5] determined that Hessian fly puparia could be eliminated if a direct pressure of 20.6 kPa (3 psi) were to be applied. The use of compression as a potential disinfestation technique for timothy hay exported to Japan is the sole reason for this study which was conducted in a commercial hay processing plant in June 2006. The objectives of this research are:

1) To analyze the pressure distribution in the compressed bale using pressure sensitive films for different applied pressures, hay qualities and hold times;

2) To determine the effectiveness of current forage compression units on attaining 100% mortality of the Hessian fly, with varying pressure, hay quality and hold times.

2 Materials and methods

2.1 Timothy hay

the past few years, he has been working in projects dealing with the utilization of flax straw as fibre reinforcement for biocomposites. He is presently working on bioplastic development from pulse starch, postharvest treatment for red lentil milling, and conversion of lignocellulosic waste into bioproducts, and many others. Dr. Tabil continues to work and have interest in projects such as agricultural waste and processing byproduct utilization and the processing of agricultural materials into industrial products. Phone: (306) 966-5317; Cell: (306) 612-3382; Fax: (306) 966-5334; E-mail: lope.tabil@usask.ca; http://www.engr.usask.ca/faculty.php?lope.tabil.

The mechanical compression unit and the timothy hays were provided by Green Prairie International, Lethbridge, Alberta, Canada. The timothy hays were grown in local farms in the Lethbridge area. Three lots of hay were used throughout the testing. These included a low-moisture first cut hay (H_1), a high-moisture first cut hay (H_2), and a high-moisture second cut hay (H_3). Specific information of the hay lots are presented in Table 1. The initial moisture contents of the low- and high-moisture hays were 9.0–10.0 and 12.0%–15.0% wet basis (w.b.), respectively, as measured by hay moisture probe (Delmhorst HTM-2, Delmhorst Instrument Co., Towaco, NJ, USA). After testing, the compressed bales were opened and samples for moisture content and color analysis were taken. The hay moisture contents measured in these tests were 9.7% H_1 and 12.7% for both H_2, and H_3. The standard deviations for the hay moisture contents of each lot were determined to be 0.4%, 1.0%, and 0.6% for H_1, H_2, and H_3, respectively.

Table 1 Hay lots used in the field tests

	Low-moisture first cut hay (H_1)	High-moisture first cut hay (H_2)	High-moisture second cut hay (H_3)
Cut	1st	1st	2nd
Producer	Greenlife Farms	GPF	Beekman
Location	Coaldale, AB	Vauxhall, AB	Coaldale, AB
Harvest date	8-Jul-04	16-Jul-05	26-Sep-05
Moisture content (% wb)	9.7	12.7	12.7
Average bale weight (kg)	650	700	710
Bale density (kg/m^3)	179.4	193.2	196.0
Color**			
L	55.6 (2.8)*	55.6 (3.8)	46.4 (3.7)
a	-1.6 (0.9)	1.3 (1.5)	0.6 (0.9)
b	19.6 (2.0)	20.8 (2.3)	15.9 (2.2)

Note: *Numbers in brackets are standard deviations; $N = 3$.
**Hunter color coordinates *L* represents lightness (0 for black and 100 for white), *a* represents redness (positive)/greenness (negative) and *b* represents yellowness (positive)/blueness (negative).

The moisture content was determined according to ASAE S358.2[14] by weighing 25 g of the hay sample and placing it in an aluminum container with a perforated cover. The samples were dried at 103°C for 24 h. After the drying process, the containers were again weighed and moisture content was calculated in percent wet basis.

The HunterLab spectrocolorimeter (Hunter Associates, Reston, VA, USA) was used to determine the color of the samples (three timothy hay lots) in terms of Hunter *L*, *a*, and *b* coordinates and the dominant wavelength. The color of the hay samples are shown in Table 1. This data suggest that H_1 was lighter and greener than the other samples. H_3 was darker than the other two samples. The mean dominant wavelength values of the hays were 574.3, 577.1, and 576.8 nm for lots H_1, H_2, and H_3, respectively. The standard deviations of these dominant wavelengths were 0.6, 1.5, and 0.2 nm for lots H_1, H_2, and H_3, respectively.

2.2 Hessian fly cages

The Hessian fly puparia infested wheat seedlings were reared at the Southern Crop Protection and Food Research Center of Agriculture and Agri-Food Canada (AAFC) located in London, ON, Canada. The pupariation was performed at temperature of (20±1) , (70±5)% relative humidity, and a light: darkness rotation of 14:10 h. The wheat seedlings were then covered with moist paper towel and placed in containers at (2.0±1) , with a light:darkness rotation of 0:24 h. The infested wheat seedlings were then dried at 30 for 24 h before being packed into the cotton organdy bags (cages). The cages were shipped from London, ON to Lethbridge, AB in styrofoam containers with wet paper towels and freezer gel packs to maintain high humidity and low temperature during transit.

A total of 360 Hessian fly cages were compressed during the experiment. Each cage contained approximately 168.56 Hessian puparia, translating into a total Hessian fly puparia count of 60681 for the entire field test (168.56 puparia/cage×10 cages/test×36 tests). An additional 36 cages which contained the same approximate Hessian puparia population were used as field controls and were not compressed. Also, 36 separate fly cages were kept by AAFC in London, ON as laboratory controls, and remained at their facility throughout the testing period.

2.3 Pressure sensitive film

Throughout the compression process, pressure sensitive films (Pressurex® Ultra Low film, Sensor Products, Hanover NJ, USA) were randomly placed at different heights, positions, and orientations within and outside the hay bale. The pressure sensitive film consists of transfer sheet (microcapsule layer) and developer sheet (color developing layer) which when pressed together can accurately detect pressures between 196-589 kPa (28-85 psi).

The films were cut to 127 mm×127 mm (5 in×5 in) square sizes and their matte sides were taped together. A few larger films were also prepared to the size of 380 mm ×270 mm (15 in×10.6 in) in order to detemine if a larger representation could be used. After removing the films from the compressed bales, they were scanned on a flatbed scanner. A pressure analysis program known as Topaq® Pressure Analysis System (Sensor Products Inc., East Hanover, NJ, USA) was used to convert the color of the films to pressure values. This was accomplished by converting the red colors into a pseudocolor pressure representation and determining what percent of the area was below 200 kPa, between 200-675 kPa and above 675 kPa.

2.4 Experimental plan for compression of timothy hay

The testing procedure included three factors: the hold time (T), applied pressure (P), and hay quality (H). The hold time corresponds to the total time that the timothy hay was held at the maximum applied pressure. This experiment included hold times of 0.5 and 2 s which were coded as T_1 and T_2, respectively. The two pressures settings were 10.34 and 12.41 MPa and were coded as P_1 and P_2, respectively. The hay quality as indicated here refers to the harvest cut number (first or second cut). The three qualities used in these experiments included: low-moisture first cut, high-moisture first cut and high-moisture second cut hay and were coded as H_1, H_2 and H_3, respectively.

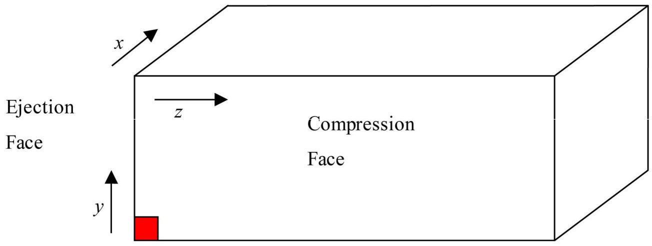
Twelve treatments were generated from the three factors and their levels. Each treatment was replicated three times. The resulting 36 tests were performed in random order.

A Hunterwood FC9322 Forage Compactor (Hunterwood Technologies Ltd., Cochrane, AB, Canada) was used for the compression (rebaling) tests. The compression unit is equipped with two 305 mm (12 in) hydraulic rams directly attached to a 1.1 m×0.4 m (43.5 in×15.75 in) plunger face. The system is capable of a maximum hydraulic line pressure of 37.59 MPa (5 452 psi), which translates into 12.41 MPa (1 800 psi) at the plunger face. Big square bales (1.2 m×1.2 m×2.4 m) are loaded onto an input table where the twines are manually removed. The bale enters the slicer box and the bale is sliced into three layers and then separated. The sliced layers are steadily moved by a conveyor to the forage compactor. A charge is weighed and loaded into the main compression chamber.

Each Hessian fly cage was prepared for compression by taping it to a pressure sensitive film and a flagging tape (to help locate the Hessian fly cage and pressure film after compression), and coding it with the specific conditions that it would be compressed under. From there, the cage-film-tape assemblies were randomly positioned in various parts of the hay charge before it entered the compression chamber (Figure 1).

Figure 1 Random manual positioning of Hessian fly cages and pressure sensitive film in the hay bales prior to rebaling

The strapped, compressed bales were ejected from the compression chamber. The dimensions and weight of the compressed hay were recorded in order to determine the bale density. After 30 min elapsed time, the straps were cut. With the help of the flagging tape attached to each cage, all of the cages and pressure sensitive films were retrieved. All the coordinates were recorded for the location of each cage and film (for purposes of brevity, the authors are not presenting the location of each cage-film-tape assembly within a compressed bale). A reference drawing can be seen in the Figure 2 with an example of the randomized location of the ten cage-film-tape assemblies in a test. The ejection face is the side of the compressed bale in contact with the eject plunger. And the compression face is the side of the bale in contact with the compression plunger.



a. Typical compressed bale dimensions (x = 0.432 m; y = 0.432 m; z = 1.168 m)

Test #	Chamber pressure /MPa	Hold time /s	Hay lot	Film #	Location		
					x/m	y/m	z/m
10	10.34	2	H_3	1	0.267	0.203	0.775
				2	0.038	0.254	0.140
				3	0.076	0.152	0.991
				4	0.127	0.152	0.152
				5	0.178	0.279	0.483
				6	0.051	0.229	0.559
				7	0.178	0.178	0.813
				8	0.279	0.254	0.584
				9	0.191	0.089	0.178
				10	0.254	0.254	0.394

b. Randomized cage-film-tape assembly location in Test 10

Figure 2 Cage and film reference location and example of randomized location of randomized cage-film-tape assembly

A humidity and temperature recording device was used during the testing. It was positioned near the compression chamber and remained there for the duration of the two day experiment. The device is capable of recording date, time of day, elapsed time, temperature, and relative humidity for long periods of time.

2.5 Pressure measurement

Pressures applied to the hay during compression were measured at two locations using pressure transducers (K - LINE, Serial number 970068, Kristal Instrumente AG Winterthur, Winterthur, Switzerland). The first pressure transducer was located on a port in the main compression ram to measure the compression pressure. While the other transducer read the pressure in the ejector ram. With these two recordings, pressures exerted on the hay and the pressure exerted by the compressed hay on the wall could be ascertained.

2.6 Hessian fly emergence

The compressed infested seedlings including the field controls were shipped back to AAFC in styrofoam containers, where they underwent a 75-day post treatment emergence. The contents of each test cage were removed and distributed over separate acetate cages. The contents of these containers were then sprayed with deionized water until wet. They were then covered to inhibit loss of moisture out of the four screened ventilation vents on opposite ends of the cages. The cages were held at a temperature of (18 ± 1) and (70 ± 5)% relative humidity with 16:8 hours of light:darkness rotation, after which, the numbers of flies emerging were recorded.

3 Results and discussion

3.1 Humidity and temperature

The humidity and temperature were recorded for both June 15 and 16, 2006. During this period, the relative humidity remained at approximately 70% until 10:00 AM where it started to decrease to 44% at 5:00 PM of June 16th. The temperature also remained at a relatively constant (16±1) from the beginning of the test to approximately 9:00 AM on June 16th. During the remaining portion of time, the temperature increased to a maximum of 20 at approximately 5:00 PM of June 16th. Figure 3 shows the temperature and humidity for the duration of the testing.

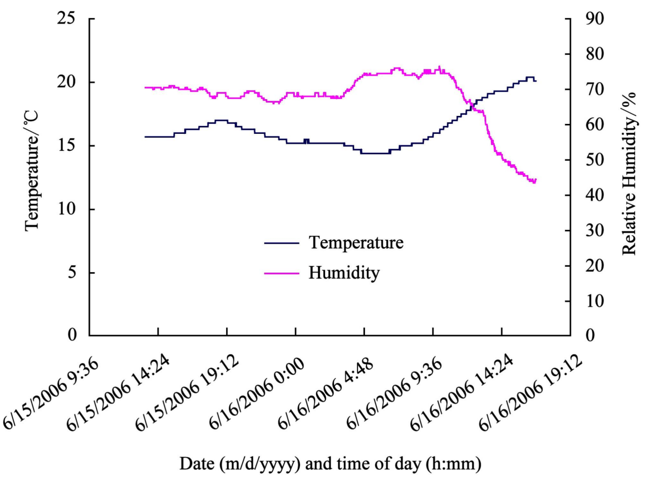


Figure 3 Temperature and relative humidity during the field test

3.2 Compressed hay physical properties

The moisture content, mass, bale density and dimensions of compressed bales are presented in Table 2.

The density of the bales after compression was calculated by weighing the bale and measuring its dimensions. The values of bale density ranged from a low of 475.0 to 612.5 kg/m^3 with a mean of 542.6 kg/m^3 and a standard deviation of 37.9 kg/m^3. The applied pressures did not affect the density and mass of the bales. The hay moisture content affected the density but did not influence bale mass. The average density of the bales was lower at moisture content of 9.7% compared to 12.7%.

Table 2 Moisture content, mass, density and dimensions of compressed bales

Hay quality, moisture content	Compression pressure of 10.3 MPa			Compression pressure of 12.4 MPa		
	Mass/kg	Density/kg m^{-3}	Dimensions/m×m×m	Mass /kg	Density/kg m^{-3}	Dimensions/m×m×m
H_3, 12.7%	121.3 (5.4)*	570.9 (22.7)	0.430 (0.007)×0.428 (0.003)× 1.157 (0.008)	118.0 (8.9)	550.4 (39.7)	0.431 (0.012)×0.428 (0.003)× 1.164 (0.003)
H_2, 12.7%	121.7 (6.2)	544.5 (46.4)	0.443 (0.018)×0.436 (0.005)× 1.159 (0.015)	122.9 (7.5)	558.4 (25.1)	0.438 (0.013)×0.435 (0.007)× 1.155 (0.012)
H_1, 9.7%	114.9 (5.9)	515.6 (29.4)	0.449 (0.015)×0.433 (0.005)× 1.148 (0.006)	118.4 (7.3)	515.8 (35.5)	0.458 (0.010)×0.432 (0.004)× 1.161 (0.007)

Note: * Numbers in brackets are standard deviations; N = 6.

3.3 Pressure in different locations of the compressed bale

All of the pressure sensitive films were assessed for the percent area below 200 kPa, between 200 kPa and 675 kPa, and above 675 kPa (Table 3). The minimum pressure reading being 200 kPa is much greater than the 20.6 kPa required to crush a single puparium[5]. Therefore, if no area fell below 200 kPa, it could be assumed that the required Hessian fly crushing force was achieved. Three tests were randomly selected to incorporate horizontal, vertical, and diagonal film positions, while for the rest of the 33 tests, vertical film positions were used. Vertical film position was adopted for the rest of the tests (33 tests) because of ease in positioning the cage-film-tape assembly and the greater possibility of damaging the films in the diagonal and horizontal positions. All of the pressure sensitive films experienced pressures greater than 200 kPa, because no area below 200 kPa was found. No matter what position or orientation of the pressure sensitive film, all of the area received pressure above 200 kPa.

Table 3 Pressure film analysis and Hessian fly emergence data for all tests

Test #	Test code	Rep.	Hold time/s	Pressure /MPa	Hay Lot #	% of Total film area*			Hessian fly emergence/%
						<200 kPa	200 - 676 kPa	>676 kPa	
1	H_3-P_2-T_2-1	1	2.0	12.41	3	0.00 (0.00)	2.02 (1.69)	97.98 (1.69)	0
2	H_3-P_2-T_1-1	1	0.5	12.41	3	0.00 (0.00)	2.26 (2.13)	97.74 (2.13)	0
3	H_3-P_2-T_1-2	2	0.5	12.41	3	0.00 (0.00)	1.70 (2.04)	98.30 (2.04)	0
4	H_3-P_2-T_2-2	2	2.0	12.41	3	0.00 (0.00)	3.53 (2.61)	96.47 (2.61)	0.12
5	H_3-P_2-T_2-3	3	2.0	12.41	3	0.00 (0.00)	4.55 (4.55)	95.45 (4.55)	0.12
6	H_3-P_2-T_1-3	3	0.5	12.41	3	0.00 (0.00)	2.48 (2.60)	97.52 (2.60)	0
7	H_3-P_1-T_1-1	1	0.5	10.34	3	0.00 (0.00)	6.70 (3.85)	93.30 (3.85)	0
8	H_3-P_1-T_2-1	1	2.0	10.34	3	0.00 (0.00)	0.81 (0.76)	99.19 (0.76)	0
9	H_3-P_1-T_2-2	2	2.0	10.34	3	0.00 (0.00)	1.79 (3.06)	98.21 (3.06)	0
10	H_3-P_1-T_2-3	3	2.0	10.34	3	0.00 (0.00)	0.89 (1.59)	99.11 (1.59)	0
11	H_3-P_1-T_1-2	2	0.5	10.34	3	0.00 (0.00)	1.18 (1.22)	98.82 (1.22)	0
12	H_3-P_1-T_1-3	3	0.5	10.34	3	0.00 (0.00)	1.85 (2.00)	98.15 (2.00)	0
13	H_2-P_1-T_2-1	1	2.0	10.34	2	0.00 (0.00)	1.48 (2.19)	98.52 (2.19)	0
14	H_2-P_1-T_1-1	1	0.5	10.34	2	0.00 (0.00)	0.61 (1.23)	99.39 (1.23)	0
15	H_2-P_1-T_2-2	2	2.0	10.34	2	0.00 (0.00)	1.01 (1.08)	98.99 (1.08)	0
16	H_2-P_1-T_1-2	2	0.5	10.34	2	0.00 (0.00)	3.62 (3.81)	96.38 (3.81)	0
17	H_2-P_1-T_2-3	3	2.0	10.34	2	0.00 (0.00)	0.37 (0.26)	99.63 (0.26)	0
18	H_2-P_1-T_1-3	3	0.5	10.34	2	0.00 (0.00)	0.91 (0.93)	99.09 (0.93)	0

Test #	Test code	Rep.	Hold time/s	Pressure /MPa	Hay Lot #	% of Total film area*			Hessian fly emergence/%
						<200 kPa	200 - 676 kPa	>676 kPa	
19	H_2-P_2-T_2-1	1	2.0	12.41	2	0.00 (0.00)	0.52 (0.48)	99.48 (0.48)	0
20	H_2-P_2-T_1-1	1	0.5	12.41	2	0.00 (0.00)	0.67(0.65)	99.33(0.65)	0
21	H_2-P_2-T_2-2	2	2.0	12.41	2	0.00 (0.00)	0.98 (1.22)	99.02 (1.22)	0
22	H_2-P_2-T_1-2	2	0.5	12.41	2	0.00 (0.00)	0.55 (0.74)	99.45 (0.74)	0
23	H_2-P_2-T_1-3	3	0.5	12.41	2	0.00 (0.00)	0.40 (0.71)	99.60 (0.71)	0
24	H_2-P_2-T_2-3	3	2.0	12.41	2	0.00 (0.00)	1.10 (0.94)	98.90 (0.94)	0
25	H_1-P_2-T_2-1	1	2.0	12.41	1	0.00 (0.00)	0.51 (0.88)	99.49 (0.88)	0
26	H_1-P_2-T_2-2	2	2.0	12.41	1	0.00 (0.00)	1.27 (1.49)	98.73 (1.49)	0
27	H_1-P_2-T_1-1	1	0.5	12.41	1	0.00 (0.00)	1.54 (1.37)	98.46 (1.37)	0
28	H_1-P_2-T_1-2	2	0.5	12.41	1	0.00 (0.00)	1.50 (1.30)	98.50 (1.30)	0
29	H_1-P_2-T_1-3	3	0.5	12.41	1	0.00 (0.00)	0.71 (1.16)	99.30 (1.16)	0
30	H_1-P_2-T_2-3	3	2.0	12.41	1	0.00 (0.00)	0.27(0.45)	99.73(0.45)	0
31	H_1-P_1-T_2-1	1	2.0	10.34	1	0.00 (0.00)	0.81(0.88)	99.19 (0.88)	0
32	H_1-P_1-T_2-2	2	2.0	10.34	1	0.00 (0.00)	1.29(1.34)	98.71 (1.34)	0
33	H_1-P_1-T_1-1	1	0.5	10.34	1	0.00 (0.00)	0.58(1.19)	99.42 (1.19)	0
34	H_1-P_1-T_1-2	2	0.5	10.34	1	0.00 (0.00)	0.74(0.70)	99.26 (0.70)	0
35	H_1-P_1-T_1-3	3	0.5	10.34	1	0.00 (0.00)	0.27(0.23)	99.73 (0.23)	0
36	H_1-P_1-T_2-3	3	2.0	10.34	1	0.00 (0.00)	1.78 (1.96)	98.22 (1.96)	0
Field control	-	-		-	-	-	-	-	5.01
Lab control	-	-		-	-	-	-	-	36.73

Note: * Values in brackets represent the standard deviation. Rep. is replication.

H – hay quality/lot; H_1 = low-moisture hay first cut; H_2 = high-moisture hay first cut; H_3 = high-moisture hay second cut.

T – hold time at maximum compression pressure; T_1 = 0.5 s; T_2 = 2 s.

P – maximum applied compression pressure; P_1 = 10.34 MPa; P_2 = 12.41 MPa.

During the preliminary testing, the large 380 mm× 270 mm (15 in×10.6 in) films were taped up against the walls of the compression chamber in order to determine if the pressure experienced on the walls could be determined. After the films were recovered from the compression chamber, it was determined that the films were damaged beyond scanning. Therefore, through visual inspection, and the condition of the films, it was concluded that pressure induced on the hay at the walls of the chamber were in excess of 200 kPa.

3.4 Hessian fly emergence

After the 75-day post-treatment emergence, the number of Hessian fly puparia that survived the compression process were calculated and presented in Table 3. Of the 60681 puparia in the entire test, only 4 survivors (0.0066%) were found. These survivors emerged from one cage in Test #4 (2 flies) and one cage in Test #5 (with 2 flies). Both of these tests involved wet second cut hay which underwent an applied pressure of 12.41 MPa (1 800 psi). The hold time of the compression unit was set to 2.0 s in Test #4 and 2.0 s in Test #5. The location of the Hessian fly cage in Test #4 was approximately 51 mm (2 in.) from the edge in the x-axis. The cage in Test #5 was approximately 76 mm (3 in.) from the edge of the z-axis. The pressure films corresponding with these cages experienced pressure all in excess of 200 kPa. However, the percent total area of the films that underwent 200 to 676kPa was greater than most of the other tests. Emergence of Hessian fly puparia in these two tests may have been caused by inadequate compression of the infested wheat stalks in the cage. Since the size of the puparium is approximately 5 mm in length[1] it may have great chances of not achieving the desired pressure of 20.6 kPa.

The field and lab controls also underwent the 75-day emergence process. The field controls had an emergence of 5.01%, while the lab controls had an emergence of 36.73%. The lower emergence of the field controls could be attributed to the extended drying of the field control samples. Yokoyama et al.[6] indicated that Hessian fly puparia did not survive field drying alone. Hay drying increases the mortality of Hessian fly puparia. This elucidates the fact that combining hay drying and mechanical compression may be an effective method to control the puparia. The drastic decline in fly emergence between the lab and field controls and that of the compressed cages confirms that this process is quite successful.

3.5 Pressure measurement in the compression and ejection rams

Pressures applied to the bales were measured at two locations. One pressure transducer measured the direct pressure applied by the compression faceplate at the main compression cylinder while the other measured the pressure exerted by the hay on the wall of the ejection ram at the main ejection cylinder. These transducers allowed for the pressure settings to be confirmed. Table 4 presents the mean and standard deviation of the maximum compression and ejector ram pressures of the 36 tests (18 tests for high pressure and 18 tests for low pressure). The mean compression ram pressures were consistently higher than the pressure setting. Furthermore, the standard deviations of these applied pressures were relatively small. Therefore, it can be concluded that the compression unit consistently applied an accurate magnitude of pressure. An average pressure value of (3.9±0.67) MPa was exerted on the ejector ram walls. This value gives the amount of pressure that is applied to surfaces of the bale during compression. Typical compression faceplate and ejector wall pressures obtained during the compression process are shown in Figure 4.

Table 4 Average maximum pressure applied on the bales by the compression and ejector rams

	High Pressure (12.41 MPa)		Low Pressure (10.34 MPa)	
	Compression ram	Ejector ram	Compression ram	Ejector ram
Mean (MPa)	12.64	3.85	10.49	3.92
St. Dev. (MPa)	0.11	0.66	0.16	0.68

Note: N = 18 (total of 36 tests; 18 tests at pressure of 12.41 MPa; 18 tests at pressure of 10.34 MPa)

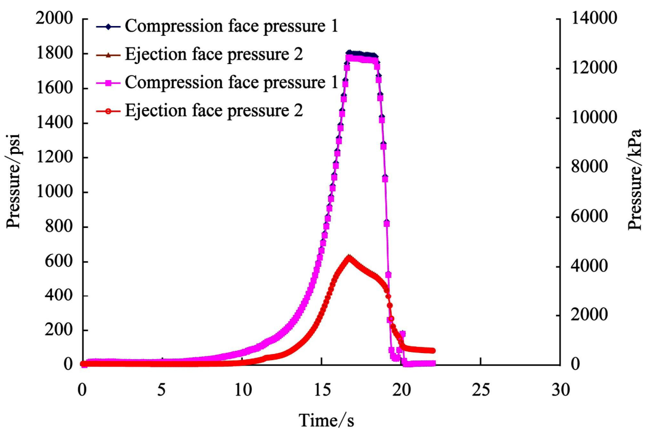


Figure 4 Typical pressure exerted on hay by the main compression and ejector rams over the duration of a test. Pressure 1 was measured by pressure transducer 1 in the compression face; Pressure 2 was measured by pressure transducer 2 in the ejection face

4 Conclusions

From the results of this study, the following conclusions can be drawn:

1) Film analysis showed that 100% of the hay experienced at least 200 kPa (29 psi). The positioning of the film, whether vertical, diagonal or horizontal, did not affect the pressure experienced nor the emergence of Hessian fly puparia.

2) Following the 75-day post experiment emergence period, 0.0066% of the puparia survived, which might be due to the fact that the emerged puparia might have not been crushed and not subjected to a pressure of at least 20.6 kPa.

3) The applied pressures had effect on Hessian fly emergence by considerably reducing the number of puparia survival. However, one Hessian fly emerged from one of the cages in two tests.

4) Most of the Hessian fly puparia were destroyed irrespective of the applied pressure, hold time or hay quality.

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