The use of chlorine dioxide for controlling stored-product insect pests a

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Background

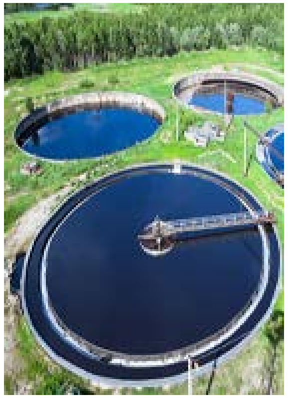
Chlorine dioxide (ClO_2) physical properties

- Melting point: - 59 °C
- Boiling point: 11 °C
- Odor: similar to chlorine
- Color: yellow-green to red (high concentration)
- Density: 2.4 times heavier than air
- Conversion: 1 mg/L = 370.63 ppm

Background

Chlorine dioxide applications

- Water treatment: legionella, beverage and food industry, odor control, oil industry, municipal and waste water treatment.
- Surface and air treatment: food processing plants, biomedical devices, hospitality, residential.

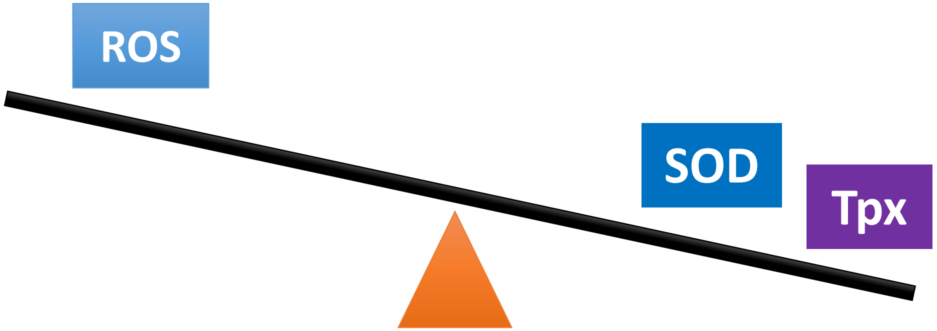
     

Background

Mode of Action of chlorine dioxide against insect pests

- Oxidative stress (Kim et al., 2015 and Kumar et al., 2015)

ClO_2 enhances the production of reactive oxygen species (ROS) inside larvae of *Tribolium castaneum* and *Plodia interpunctella*. It also causes more antioxidant enzymes (superoxide dismutase and thioredoxin-peroxidase) being synthesized by gene up-regulation. However excess ROS eventually accumulates and imposes oxidative stress to cells, which leads to the lethal effect.



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Responses of phosphine susceptible and resistant strains of five stored-product insect species to chlorine dioxide

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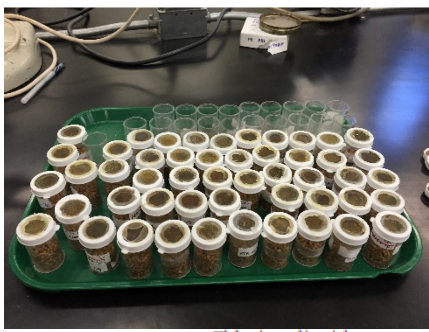

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Chlorine dioxide

A B S T R A C T

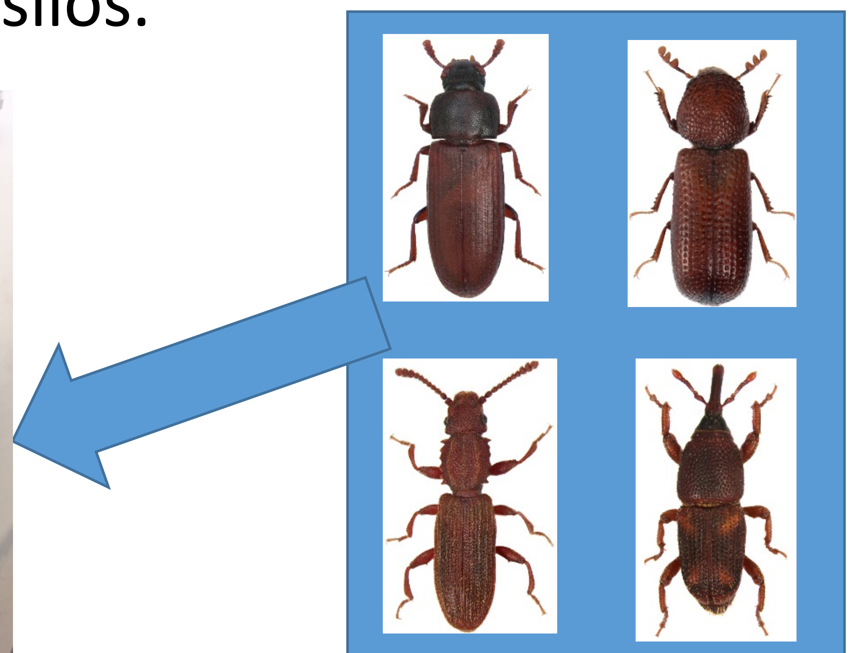
Adults of phosphine susceptible laboratory strains and phosphine resistant field strains of five stored-product insect species were exposed in vials with 0 or 10 g of wheat for different time periods to 0.54 g/m^3 (200 ppm) of chlorine dioxide gas. After exposure, adult mortality was determined 5 d later at 28 °C and 65% r.h. The 5-d mortality was 100% in laboratory and field strains of the red flour beetle, *Tribolium castaneum* (Herbst); sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.); lesser grain borer, *Rhyzopertha dominica* (F.); maize weevil, *Sitophilus zeamais* Motschulsky; and rice weevil, *Sitophilus oryzae* (L.) that were exposed in vials with 10 g of wheat to chlorine dioxide for 26, 16, 24–34, 18–24, and 15–18 h, respectively. Corresponding exposure durations for these species and strains in vials without wheat were 15, 3, 18–20, 7–15, and 5–7 h, respectively. Dosages of chlorine dioxide producing 99% mortality (LD_{99}) of *T. castaneum*, *O. surinamensis*, *R. dominica*, *S. zeamais*, and *S. oryzae* strains in vials with wheat ranged from 14.79–22.57, 8.20–8.41, 15.79–21.60, 10.66–14.53, and 7.67–12.20 g-h/m^3, respectively. In vials without wheat, corresponding LD_{99} values for *T. castaneum*, *R. dominica*, and *S. zeamais* strains were 6.51–8.66, 11.46–23.17, and 5.79–10.26 g-h/m^3, respectively. LD_{99} values for *O. surinamensis* and *S. oryzae* could not be computed, because of 100% mortality after a 3–5 h exposure to chlorine dioxide. No adult progeny production of *T. castaneum* and *O. surinamensis* was observed after 8 weeks in control and chlorine dioxide-exposed samples. Adult progeny production of *Sitophilus* spp. was found only in the control samples. The dosage for 99% adult progeny reduction relative to control for *R. dominica* strains ranged from 10.07 to 18.11 g-h/m^3. Chlorine dioxide gas is effective in killing phosphine susceptible and resistant strains of five stored-product insect species and suppressing adult progeny production of three out of the five species.

Exposure times required for complete mortality of adults of five stored-product insect species at 0.54 g/m^3 of chlorine dioxide based on mortality assessments made 5 d after the exposure.

Species	Strain	Exposure time (h)	
		with wheat	without wheat
T. castaneum	LAB	26	15
	AB1	26	15
	MN	26	15
O. surinamensis	LAB	16	3
	AB2	16	3
R. dominica	LAB	24	20
	CS	34	18
	RL	34	20
S. zeamais	LAB	24	15
	TX	18	7
S. oryzae	LAB	15	5
	TX	18	7

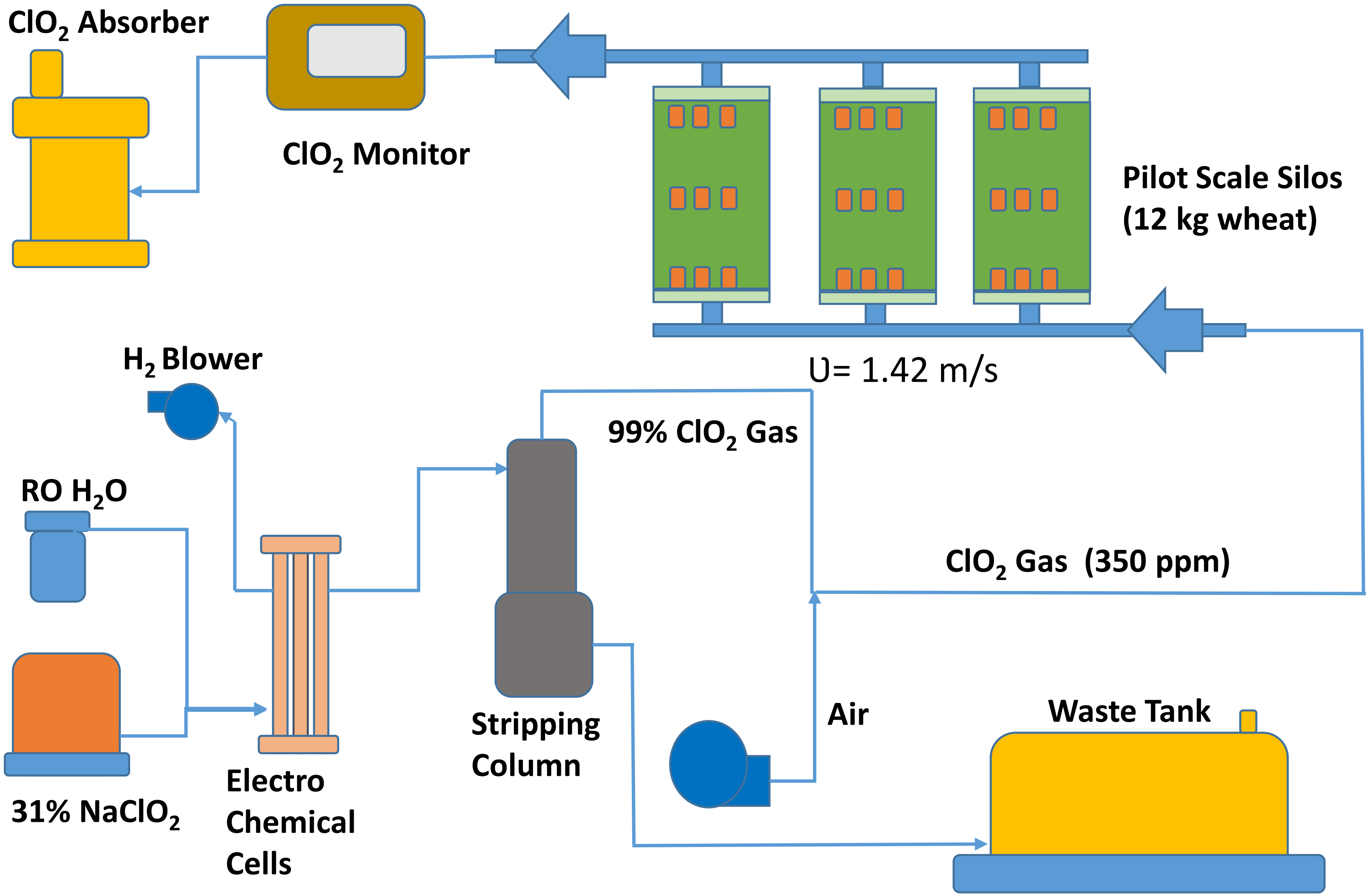
Objectives

1. Investigate the chlorine dioxide gas penetration property in wheat.
2. Compare the efficacy of chlorine dioxide in killing insects located at different depths in the pilot-scale model silos.



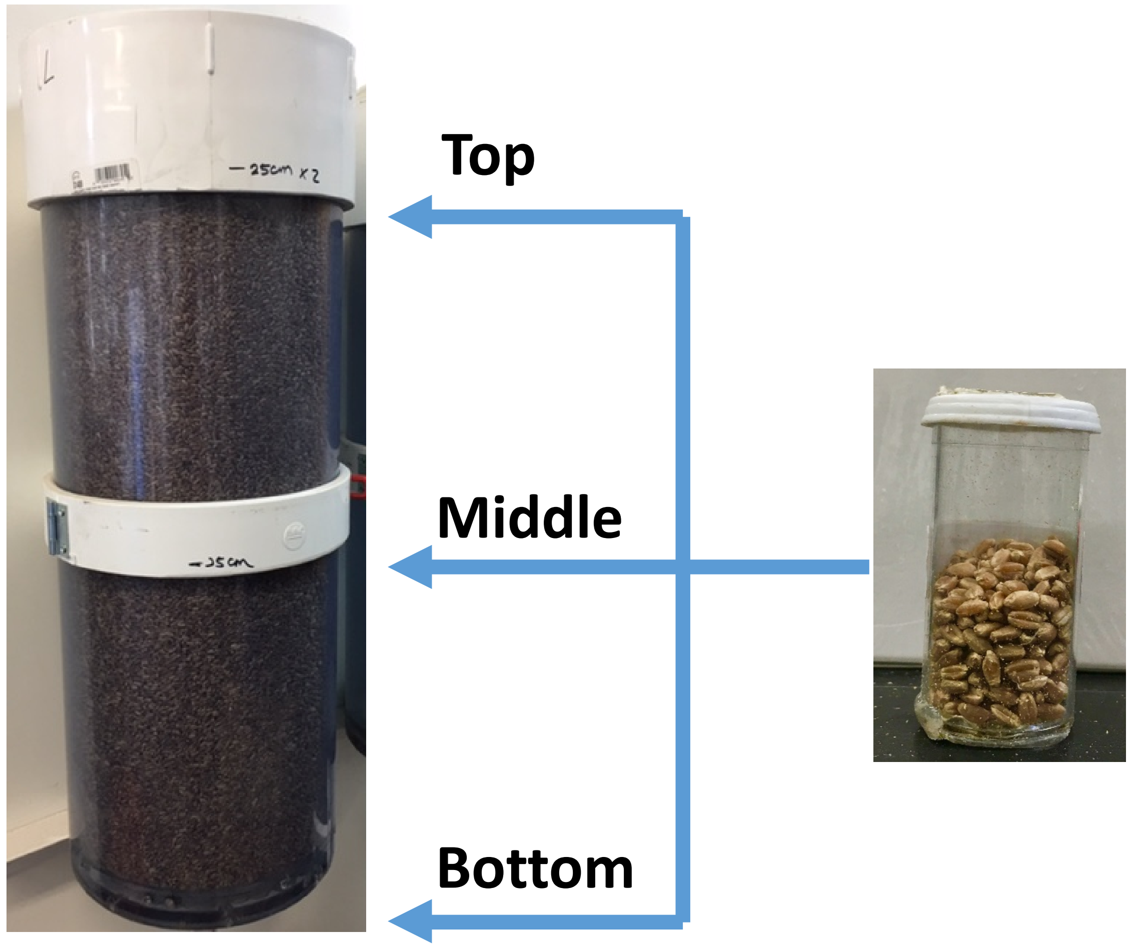
Experiment setup

$$2NaClO_2 + 2H_2O = 2ClO_2 + 2NaOH + H_2$$



Species and strains used in this study

Species	Strain	County, state	Collection year	Resistance status
Tribolium castaneum	LAB	Laboratory	1999	susceptible
	MN	Ottawa, Kansas	2011	strong
Rhyzopertha dominica	LAB	Laboratory	1999	susceptible
	FL	Bella Glade, Florida	2007	strong
Oryzaepilus surinamensis	LAB	Laboratory	1999	susceptible
	AB2	Abilene, Kansas	2011	weak
Sitophilus zeamais	LAB	Laboratory	1999	susceptible
	TX	Texas	2011	weak

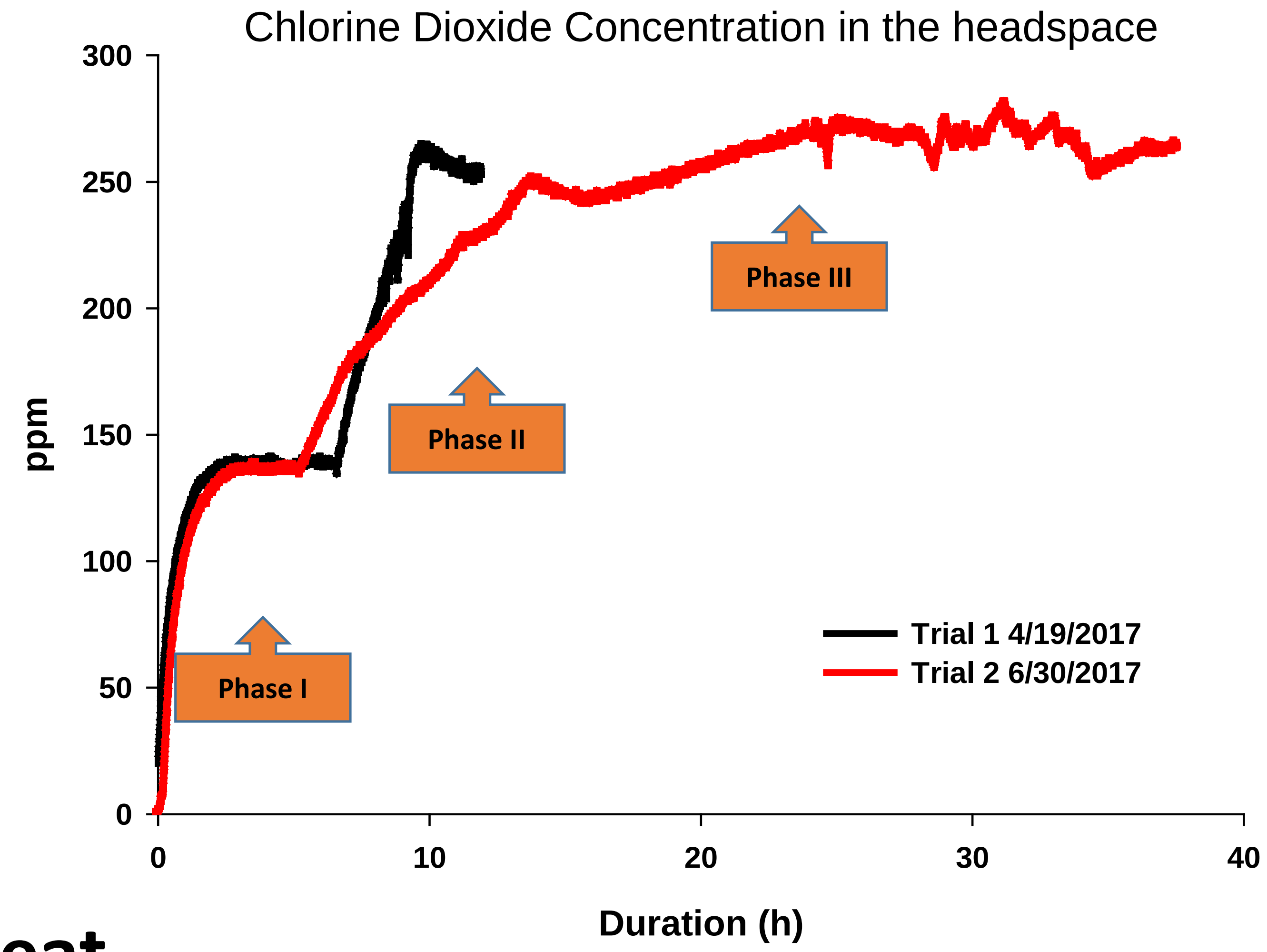


10 g of wheat

20 insects of each strain and species

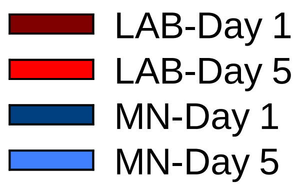
Diameter : 20 cm
Height: 50 cm
Capacity: 12 kg wheat or 11.3 kg corn

Results *Initial Exposures*

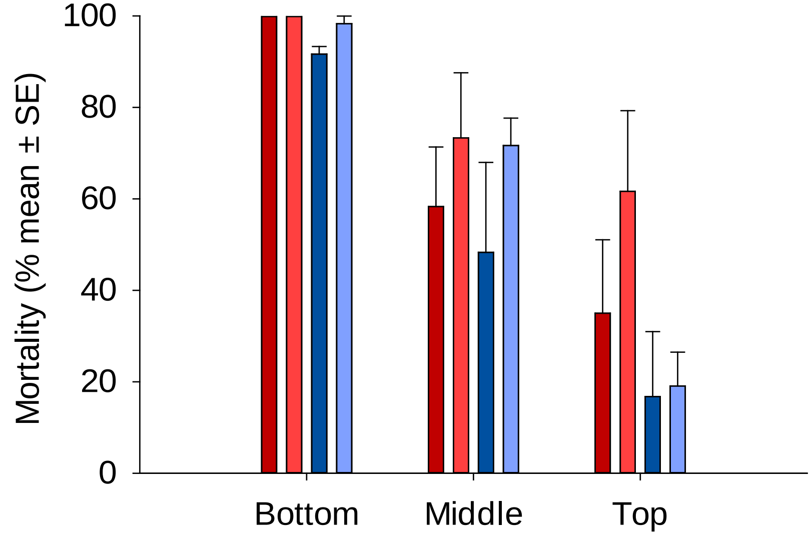


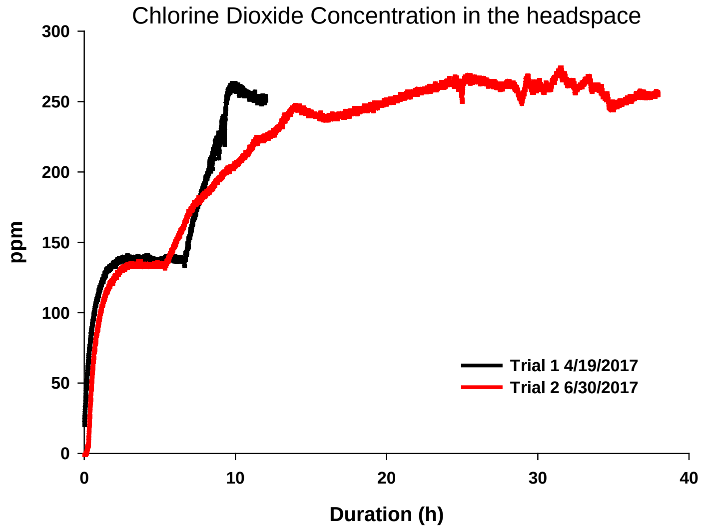
Wheat

T. castaneum
Red flour beetle

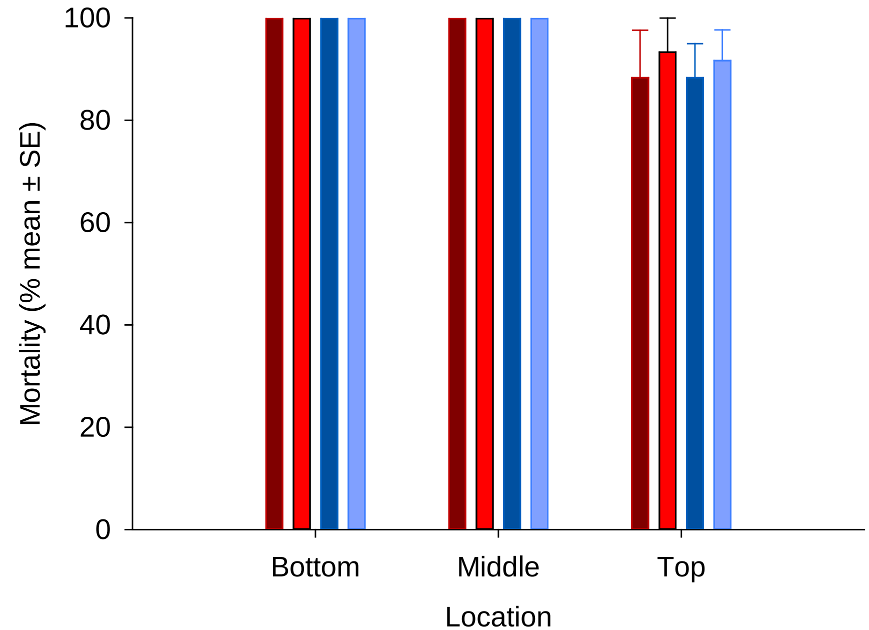


Trial 1





Trial 2

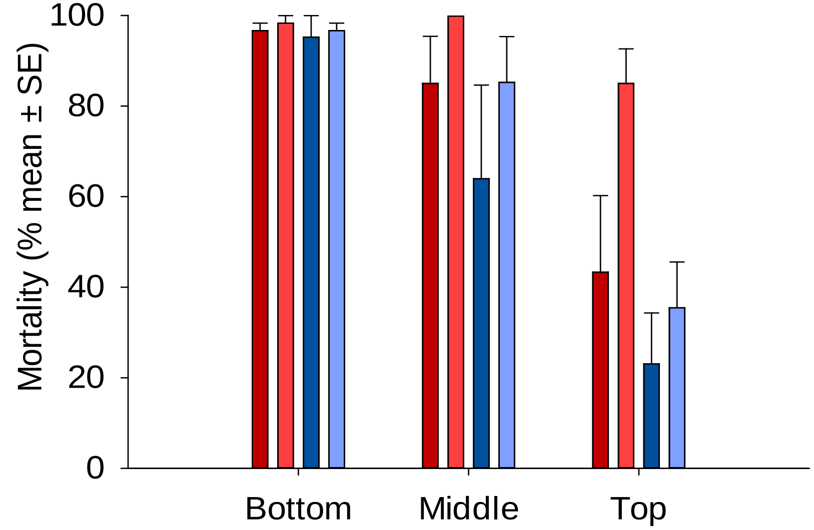


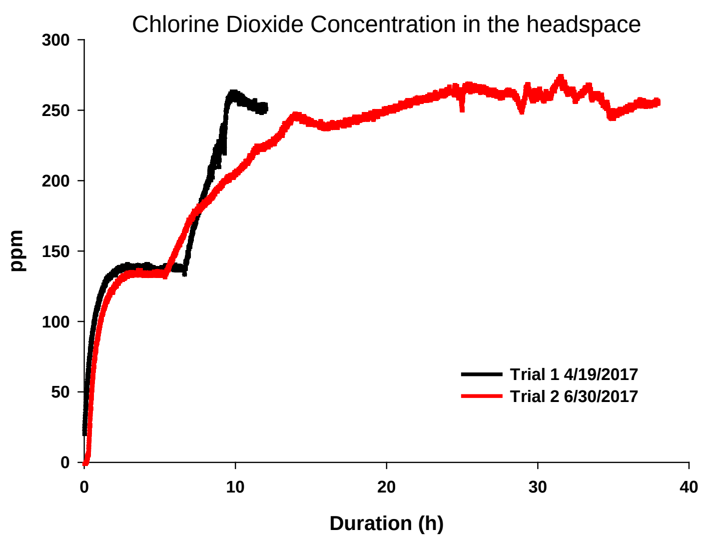
R. dominica

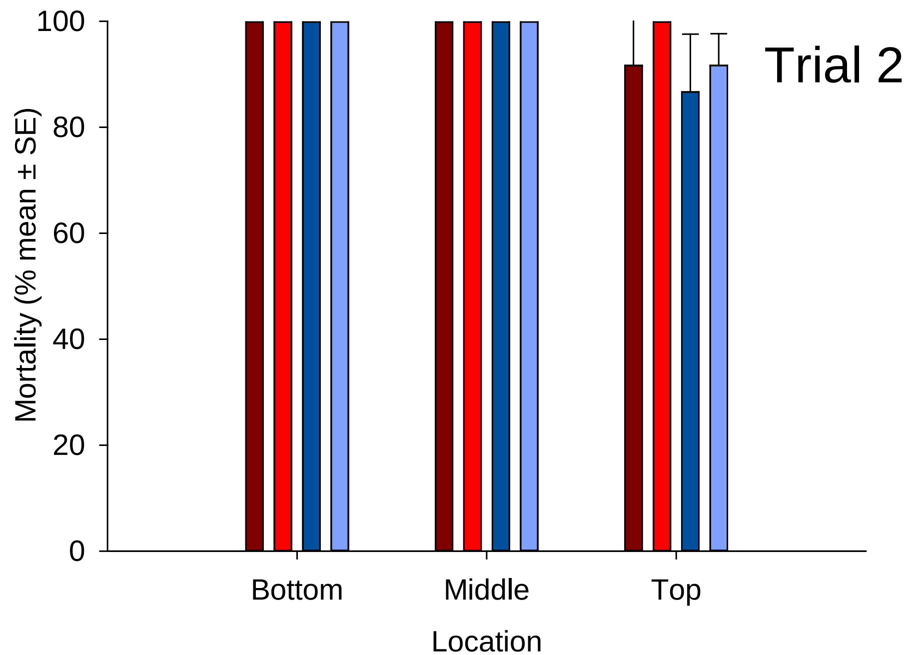
Lesser grain borer

LAB-Day 1
LAB-Day 5
FL-Day 1
FL-Day 5

Trial 1



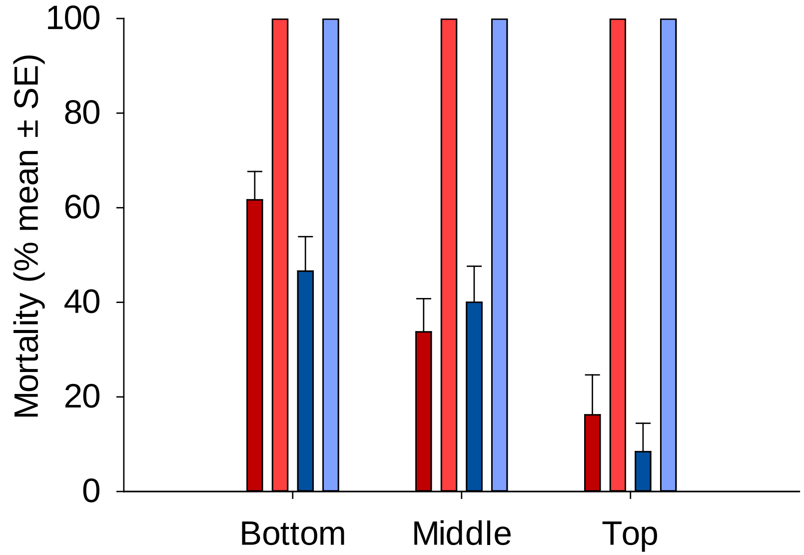


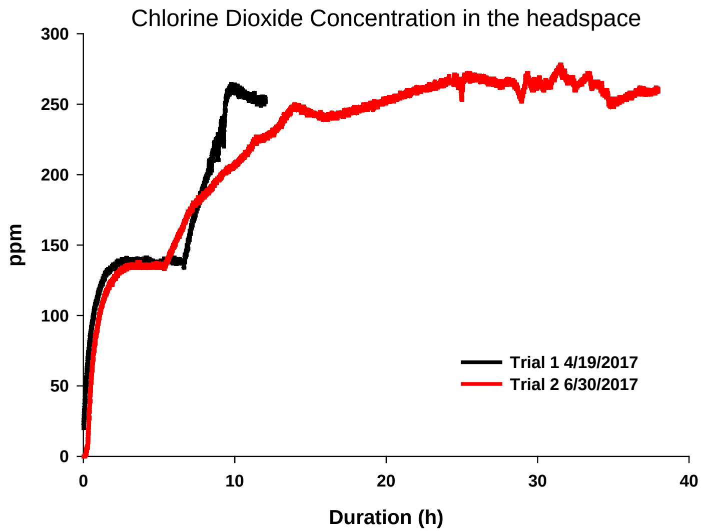


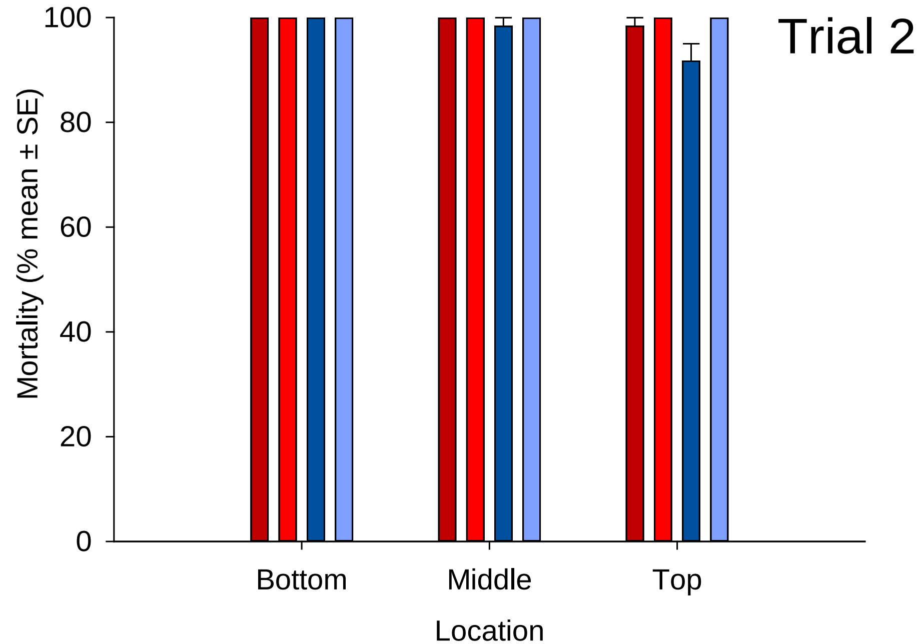
S. zeamais
Maize weevil

LAB-Day 1
LAB-Day 5
TX-Day 1
TX-Day 5

Trial 1

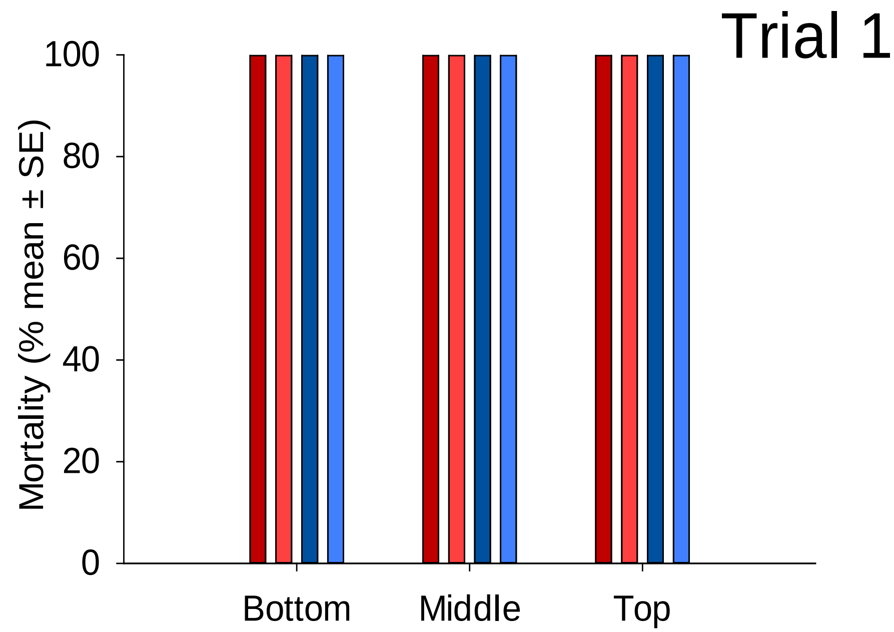


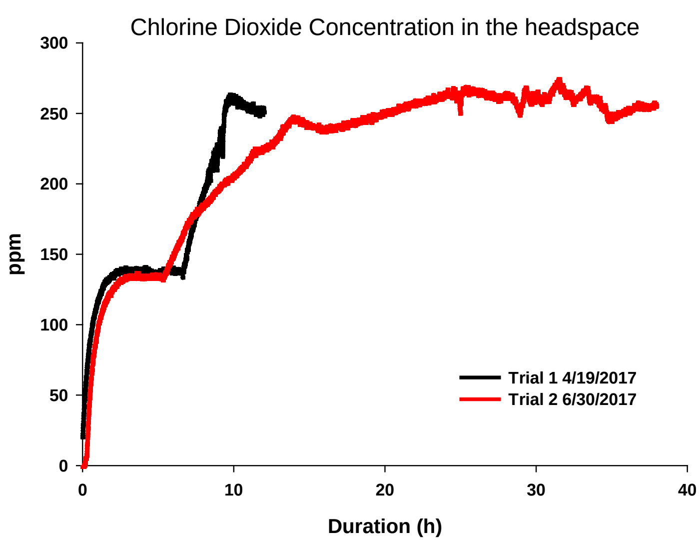


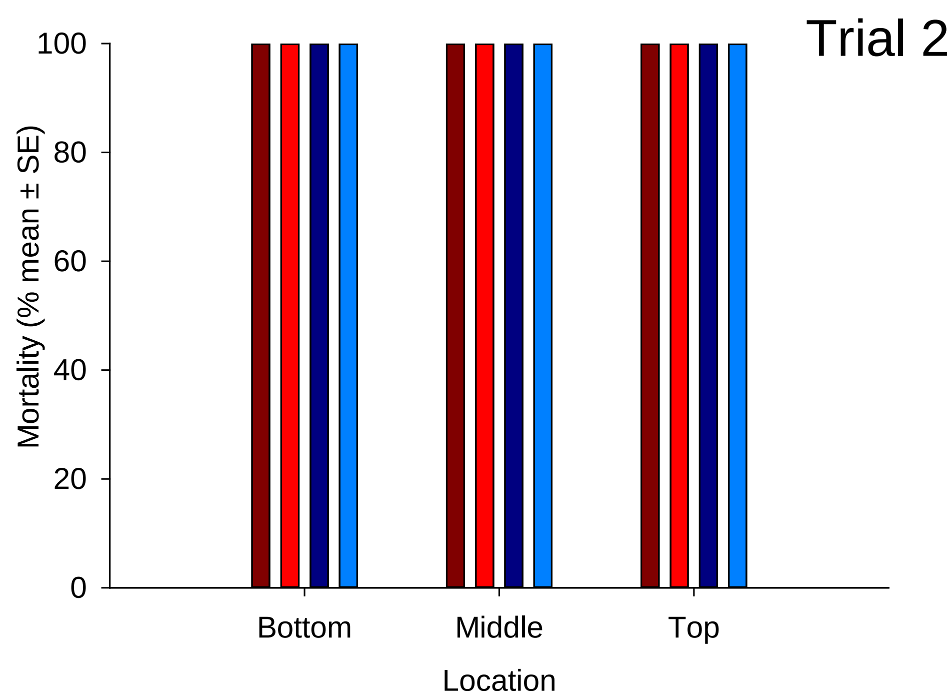


O. surinamensis
Sawtoothed grain beetle

LAB-Day 1
LAB-Day 5
AB2-Day 1
AB2-Day 5





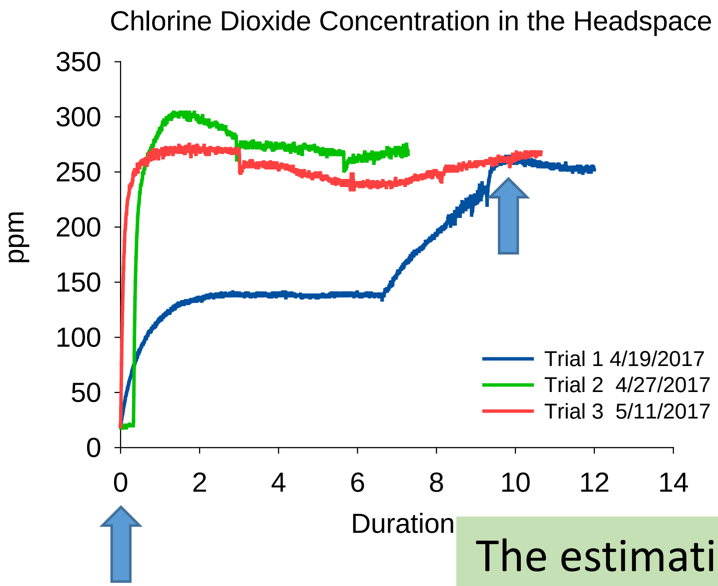


Progeny production in control and chlorine dioxide treated samples

Trial #1	**Position**			
Strain	**Control**	**Bottom**	**Middle**	**Top**
***T. castaneum*-LAB**	**5.7 ± 4.7 AB**	**0 ± 0 B**	**114.3 ± 45.2 A**	**66.0 ± 33.1 AB**
***T. castaneum*-MN**	**11.3 ± 4.1 B**	**0 ± 0 C**	**75.0 ± 11.1 A**	**58.7 ± 6.6 A**
***R. dominica*-LAB**	**89.3 ± 35.8 A**	**0 ± 0 B**	**0 ± 0 B**	**7.0 ± 7.0 B**
***R. dominica*-FL**	**3.3 ± 2.8 AB**	**3.0 ±2.1 B**	**7.7 ± 7.7 AB**	**37.0 ± 8.2 A**
***O. surinamensis*-LAB**	**107.0 ± 18.2 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***O. surinamensis*-AB2**	**148.3 ± 11.8 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***S. zeamais*-LAB**	**2.3 ± 0.9 A**	**0 ± 0 B**	**0 ± 0.3 B**	**0 ± 0.6 B**
***S. zeamais*-TX**	**2.0 ± 2.5**	**0 ± 0**	**0 ± 0**	**0 ± 0**

Trial #2	**Position**			
Strain	**Control**	**Bottom**	**Middle**	**Top**
***T. castaneum*-LAB**	**4.3 ± 2.3 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***T. castaneum*-MN**	**6.0 ± 2.9 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***R. dominica*-LAB**	**21.7 ± 21.2 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***R. dominica*-FL**	**89.3 ± 14.9 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***O. surinamensis*-LAB**	**154.0 ± 9.0 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***O. surinamensis*-AB2**	**199.0 ± 15.1 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**
***S. zeamais*-LAB**	**23.0 ± 11.4 A**	**0 ± 0 B**	**0 ± 0 B**	**0.3 ± 0.3 B**
***S. zeamais*-TX**	**2.0 ± 1.5 A**	**0 ± 0 B**	**0 ± 0 B**	**0 ± 0 B**

Estimation of chlorine dioxide usage



ClO_2 feeding concentration: 350 ppm
Density of ClO_2 is 2.94 kg/m^3
Gas flow rate = 0.073 m^3/min
To saturate 36 kg of wheat, 10 h of gas flow is needed.

The estimation of ClO_2 use to saturate 36 kg of wheat (completion of phase I and II) is calculated as following:
$m_{ClO2} = \rho \times V = 0.051$ kg

Wheat

To saturate one ton of wheat, 1.41 kg of ClO_2 will be needed. To maintain the ClO_2 concentration of 350 ppm inside the one ton of wheat for another 12 h, the maximum ClO_2 consumption is approximately 1.72 kg. If the silo is sealed well, and equipped with a recirculation fan, the ClO_2 usage can be significantly reduced.

Wheat Quality

Wheat used in trial 1 was tested for quality assessment.

It was exposed to a chlorine dioxide concentration of 350 ppm three times with a total exposure duration of 30 h.

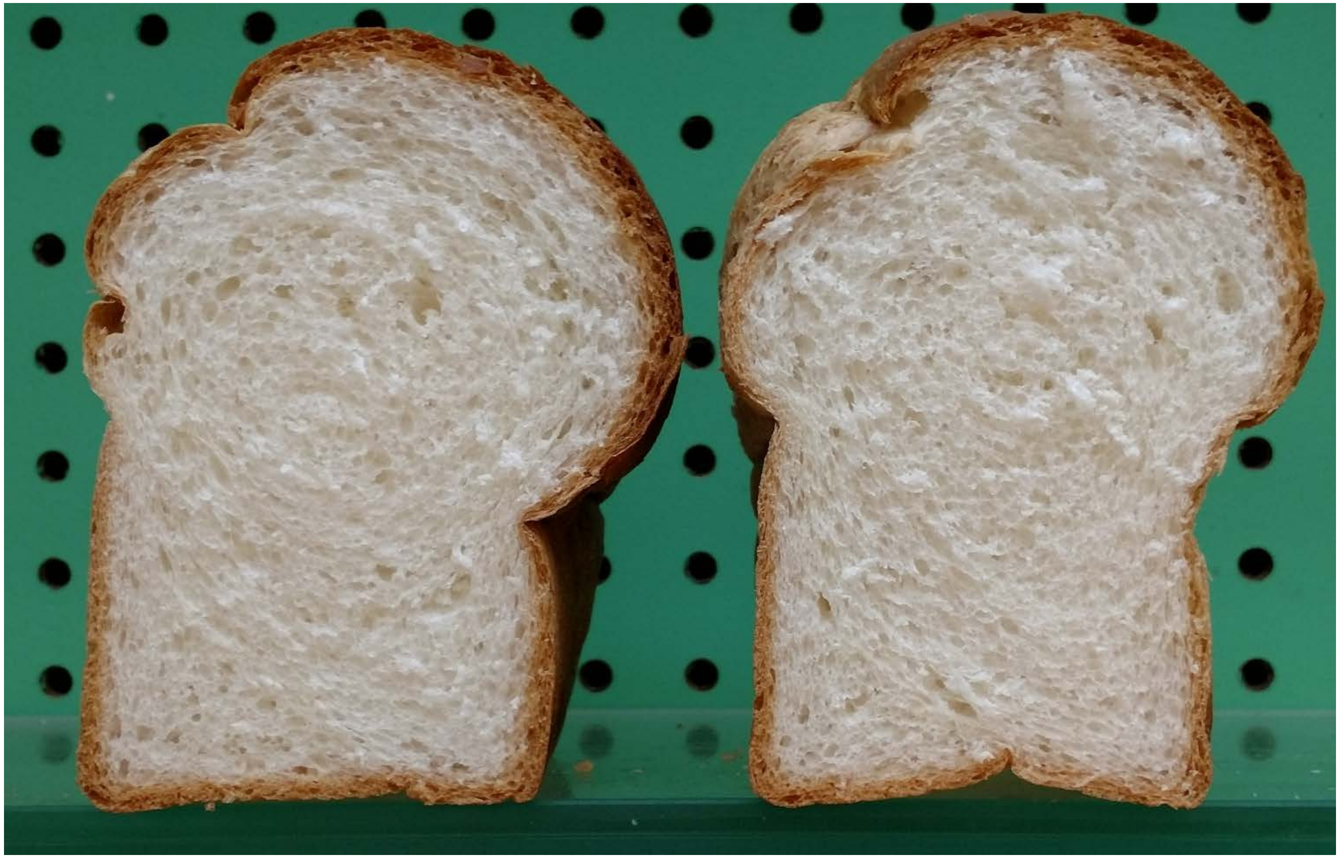
All quality parameters were measured based on AACC International Methods.

Wheat	Control	ClO_2 treated
Moisture (%)	11.24	10.83
Protein (%, 12 % mb)	13.20	13.07

One replication.

Wheat flour	Control	ClO_2 treated
Moisture (%)	15.67	15.51
Protein (%)	11.85	11.99
pH	5.44	5.37
Milling yield (%)	63.0	64.6
Farinograph		
Absorption (%)	62	61
Peak Time (min)	6.6	7.1
Stability (min)	>15	>15
Mixograph		
Absorption (%)	62	62
Peak Time (min)	3.6	4.4
Bread		
Absorption (%)	62	62
Mix Time (min)	3.25	4.0
Loaf Volume (cc)*	948 ± 14	940 ± 26

*Three replications. Otherwise one replication.



Control **Treatment**

The use of chlorine dioxide in controlling immature stages of stored-product insect pests: A laboratory scale study

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Results

Chlorine dioxide (350 ppm) exposure durations (h) for each strain and stage to obtain complete mortality

R. dominica	Eggs	Young larvae	Old larvae
LAB	2	4^{*} (93.5%)	8^{*} (95.9%)
CS	2	10^{*} (94.3%)	8^{*} (93.1%)
FL	2	10^{*} (94.9%)	10^{*} (92.2%)
PD	2^{*} (98.5%)	6^{*} (96.5%)	4^{*} (98.1%)
RL	2^{*} (96.9%)	8^{*} (95.1%)	10^{*} (91.0%)

S. zeamais	Eggs	Old larvae	Pupae
LAB	2	6^{*} (58.7%)	10^{*} (68.2%)
TX	2	6^{*} (65.5%)	10^{*} (69.6%)

Results

Chlorine dioxide (350 ppm) exposure durations (h) for each strain and stage to obtain complete mortality

O. surinamensis	Eggs	Young larvae	Old larvae	Pupae
LAB	2	2	10^{*} (45.3%)	10^{*} (33.3%)
AB2	2	2	10^{*} (65.3%)	10^{*} (45.3%)

P. interpunctella	Eggs	Fifth instars	Pupae
LAB	2^{*} (95%)	6	10^{*} (50%)

Conclusions

1. Eggs and young larvae are most susceptible to chlorine dioxide exposure, and within 6 h of exposure to chlorine dioxide at 350 ppm, complete mortality was observed for all tested species and strains.

2. Old larvae and pupae are less susceptible to chlorine dioxide exposure, especially for *O. surinamensis* strains, where after 10 h of exposure to chlorine dioxide at 350 ppm, the mortality was less than 45%.

Acknowledgement

PureLine