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Ozone fumigation in stored paddy: Changes in moisture content upon storage

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Abstract
Ozone is a highly reactive gas with insecticidal properties. The objective of this study was to determine the efficacy of ozone gas against *Rhyzopertha dominica* adults in paddy grains. Trials were conducted using ozone gas at three different concentrations and two different moisture contents in order to achieve complete mortality of the adult insects. The treated paddy grains were stored for two months and variations in moisture content upon storage were determined. The results indicated that exposure time of ozone required to achieve 100 per cent mortality of *R. dominica* adults in paddy grains at a moisture of 12.40% (w.b.) were 540, 360 and 270 min at 500, 1000 and 1500 ppm of ozone respectively. Grains at the moisture content of 14.20% (w.b.) treated under the same conditions required 610, 390 and 300 min respectively to achieve 100 percent mortality.

Keywords: Paddy, ozone, *Rhyzopertha dominica,* insect infestation, insect mortality, moisture content

1. Introduction
Paddy is the most important crop in India for domestic consumption and continues to be an important source of food. However, in the recent years insect infestation within the stored product has become a major concern to the grain industry which creates serious quality issues in stored paddy. Taking the commercial section of grain storage, where large volumes of grain are held for long periods, potential for loss is extremely high and is directly summable in financial terms [1]. Also, consumers are increasingly demanding better quality grain that is free from live insects and chemical residues caused by controlling pests. The currently available chemical fumigants are not environment friendly and also insects are found to develop resistance to these chemicals. With limited control options and increased potential for resistance to current insecticides, alternate methods are needed for management of insects in stored grains.
Ozone is a potent fumigant of stored grain. It is a strong oxidant generated electrically. The electrical generation of ozone eliminates the handling, storage, and disposal problems of conventionally used post-harvest pesticides. This attribute makes ozone an attractive candidate for controlling insects and fungi in stored grain. Initial research on ozone gas as a fumigant for storing grain has shown some promise [2]. This study was conducted to further evaluate the effect of ozone treatment on mortality of *Rhyzopertha dominica* in stored paddy.
Three levels of ozone concentration (500, 1000 and 1500 ppm) and two levels of grain moisture content (12.40% and 14.20% w.b.) was used throughout the study to determine the effect of ozone on mortality of insects.

2. Materials and Methods
The details of paddy grains, ozone fumigation setup and insects used are discussed below:

2.1 Ozone fumigation system
Ozone experimental setup consists of an oxygen concentrator, ozone generator, ozone analyser and ozone destructor. General characteristics of each component are given below:

a) Oxygen concentrator: The Oxygen concentrator (Invacare perfectO_2 - IRC5PO2V) used for the experiment makes use of molecular sieve and pressure swing adsorption methodology to produce oxygen gas as output. Ambient air entering the device is first filtered to remove traces of nitrogen and other gases from air, and is then compressed. The air after compression is directed towards one of the two nitrogen absorbing sieve beds. The device operates at 230 V

AC, 50 Hz supply with power consumption of 300 W and has a maximum flow rate of 5 lpm. Oxygen concentration level of output gas ranged from 87 to 95.6%.

b) Ozone generator: Ozone generator (Faraday Ozone - L30G) having a dimension of 420 x 210 x 370 mm operates using an air cooled ozone cell. The generator has a maximum ozone production of 30 g/h and power consumption of 230 W. The generator works on the principle of corona discharge method of generating ozone. The flow of oxygen from concentrator into the generator is controlled by a flow meter which is attached to the generator. The pure oxygen supplied is split and converted into ozone with the help of an electrode provided in the generator. The generated ozone can be supplied to the product containing the system for treatment.

c) Ozone analyzer: The ozone analyzer (BMT MESSTECHNIK GMBH - BMT 964) used is a microprocessor based dual beam photometer for measuring the content of ozone. The device has a maximum power consumption of 15 W with a voltage range of 12 to 36 V DC. The analyzer measures UV radiation in the measurement channel, UV radiation in the reference channel, temperature and pressure in the cuvette. Ozone concentration is displayed in percentage weight of ozone (% wt/wt), grams of ozone per normal cubic meter of sample gas (g/Nm^3) or ppm$_v$ on a 16 character alphanumeric display.

d) Ozone destructor: The Faraday ozone destructor unit (Faraday Ozone - DES OZ-01) is a durable 304 stainless steel chamber connected with the ozone analyser using 6 mm fittings that easily converts used ozone gas into oxygen before venting into the atmosphere. Technical specifications are: Power input-230 V AC, 50 Hz, Power consumption- 25 W, Operating range- 10 g/h. The unit utilizes thermal-catalytic method to remove excess ozone. The catalyst used is a transition MnO_2 material, because it is not consumed by ozone gas and acts as a true catalyst. Ozone destructor unit turns ozone back into oxygen and eliminates the need for complicated and costly external ducting.

2.2 Experimental procedures

A pilot scale study was conducted in a commercial stainless steel grain bin filled with 15 kg of paddy (CO 51) to estimate the mortality rates of *R. dominica* adults corresponding to different exposure times. To distribute ozone gas throughout the bulk of the grain an L-shaped perforated PVC pipe was placed vertically at the centre of the bin, such that it covered the entire bin depth. Schematic representation of the bin used is shown in Fig 1. Paddy was fed into the bin and insect cages positioned at the bottom, middle and top locations.

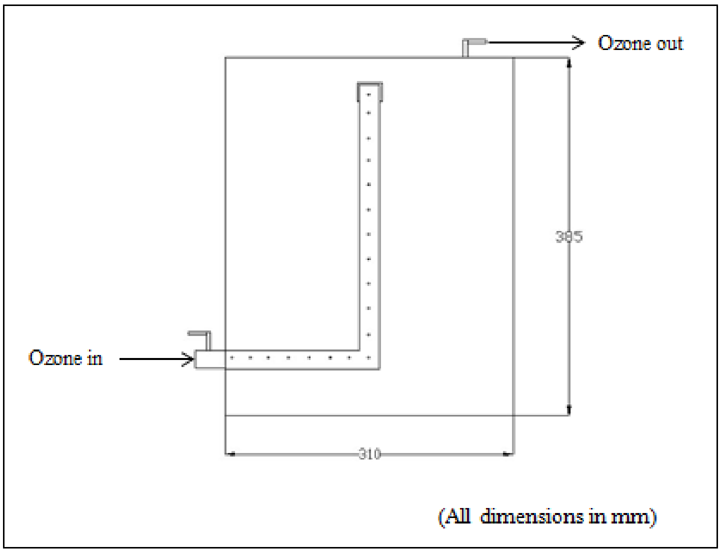

Fig 1: Household level storage bin

Insect cages were made in cylindrical shape using acrylic material with dimensions 40 x 50 x 3 mm (height x diameter x thickness). Bottom portion of the cage was covered using filter cloth in order to allow ozone gas to enter through beneath. 30 g of paddy was filled into the cage along with and 20 insects. The top end of the cage was then covered using khada cloth and tightened with cotton threads before positioning into the bin.

Flow rate was set to 4 lpm in the oxygen concentrator and ozone gas was allowed to pass from the generator to the bin. Trials were conducted at three different concentrations (500, 1000, 1500 ppm) by adjusting the ozone variable knob positions. The used up ozone gas from the outlet of the bin was sent to the ozone destructor for safe disposal.

Three levels of ozone concentration (500, 1000 and 1500 ppm) and two levels of grain moisture content (12.40% and 14.20% w.b.) was used throughout the study to determine the mortality of insects. Insects were removed after every 30 min and exposure time taken for complete mortality of insects was determined. The mortality rate of insects was calculated by using the formula given below [3].

$$\text{Mortality (\%)} = \frac{\text{No. of dead insects}}{\text{Total no of insects}} \text{x} 100$$

Treated paddy samples along with control were collected before storage and at monthly intervals during the storage period, to analyse any variations in moisture content.

2.3 Determination of moisture content

Hot air oven method was used for moisture content determination. The samples were kept in the oven maintained at 130 °C ±1 °C until constant weight was attained. The moisture content was calculated as per AOAC method (2000)

[4].

The amount of moisture to be added over the level of equilibrium moisture was calculated using the equation;

$$Q = W\frac{(M_f - M_i)}{(100 - M_f)} \qquad \text{-----3.1}$$

Q: weight of water to be added, g
W: initial weight of sample, g
M_f: desired moisture content of the sample, % (w.b.)
M_i: initial moisture content of the sample, % (w.b.)

Calculated amount of distillate water was added to the samples and then packed in polyethylene bags. The samples were stored in a refrigerator (4°C) for attaining equilibrium. The samples were removed from the refrigerator after one week duration and kept at room temperature before conducting experiments.

2.4 Statistical analysis

The lethality time required to achieve 50 and 99 per cent mortality for different ozone concentrations were calculated using Probit analysis (SPSS 16.0).

3. Results and Discussions

3.1 Mortality of *R. dominica* adults in paddy grains stored in household bins

The results of mortality studies of *R. dominica* adults for various ozone concentrations in household bin is shown in Fig. 2. From the figure it was observed that mortality rates increased with increase in the concentration of ozone.

Similar results were reported while determining the susceptibility of stored product insects to high concentrations of ozone at different exposure intervals [6]. It is also reported that much higher concentrations and longer exposure time was needed to obtain full control of insects [7].

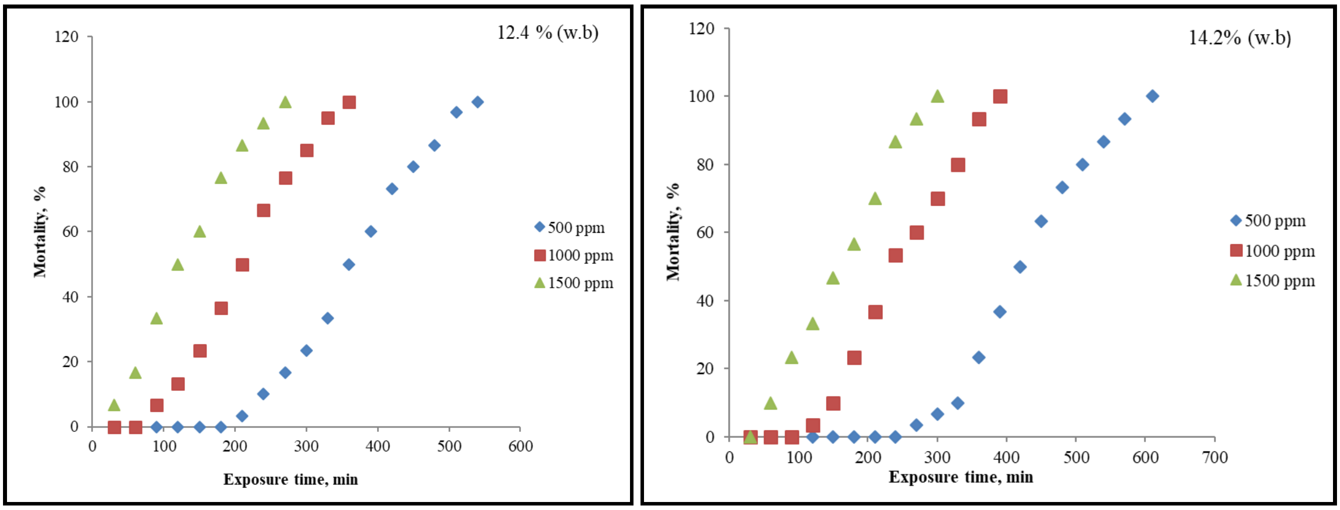

Fig 2: Mortality of *R. dominica* adults in paddy for various ozone concentration and exposure time

The exposure time required for achieving complete mortality of insects at different ozone concentration and moisture content is presented in Table 1. From the table it was found that highest exposure period of 610 min was required when concentration of ozone was 500 ppm and moisture content (w.b.) of paddy was 14.2%. Among the two moisture contents (12.4% and 14.2% w.b.), time taken for 100 per cent mortality of *R. dominica* adults was less at lower moisture content. It was deduced that at higher moistures the movement of ozone within grain layers is slowed down which requires more exposure time for insect mortality. Studies have shown that the exposure time becomes higher during moist conditions [8].

Table 1: Exposure time required at different moisture contents for achieving complete mortality of *R. dominica* adults

Ozone concentration (ppm)	Moisture content (%) (w.b.)	Exposure time (min)
500	12.4	540
	14.2	610
1000	12.4	360
	14.2	390
1500	12.4	270
	14.2	300

Probit analysis of adults was also studied, the results of which are mentioned. It was observed that the lethal time progressively decreased with increasing ozone concentration. LT_{50} and LT_{99} values recorded for 12.4% moisture content (w.b.) at 500, 1000 and 1500 ppm were 365.513, 207.813 and 126.752 min; 566.587, 376.234 and 289.271 min respectively. At 14.2% moisture content LT_{50} and LT_{99} values were 428.322, 246.951 and 158.673 min; 626.265, 422.494, and 328.213 min at 500, 1000 and 1500 ppm, respectively.

3.2 Effect of ozone gas on moisture content of stored paddy grains

The effect of ozone concentration on moisture content of paddy during storage is presented in Fig. 3 From the figure it was found that moisture content of ozone treated paddy decreased during storage. Paddy at 12.40% moisture content (w.b.) treated with ozone at 500, 1000 and 1500 ppm had moisture content of 12.06, 11.66 and 11.46% respectively on the 60th day of storage. Similarly, grains initially at 14.20% moisture content (w.b.) when treated at the above concentrations had 13.82, 13.20 and 13.05% (w.b.) moisture content on 60th day of storage. The moisture content of the control sample initially at 12.40% and 14.20% (w.b) was found to be 12.20 and 13.90% respectively on the 60th day.

The drop in moisture content might have occurred as a result of oxidation of paddy grains due to the presence of ozone gas. Similar studies have reported the same [9]. It was concluded that ozone caused oxidation to rice kernels which eventually lowered the surface moisture of rice. This is an added advantage to pest control management as lower moisture content discouraged insect infestation in the grain.

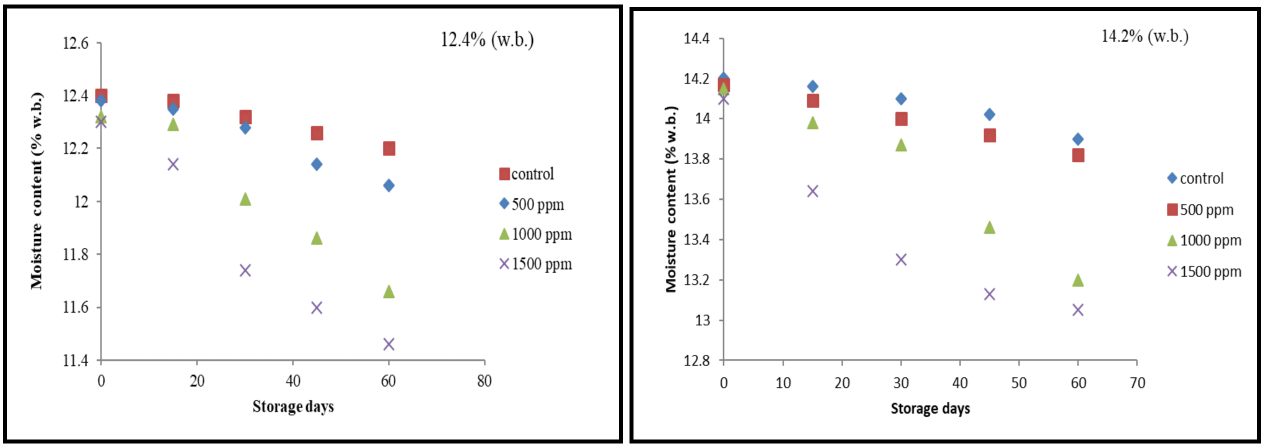

Fig 3: Effect of ozone concentration and storage days on moisture content of paddy

4. Conclusion

In household bin study, 100 per cent mortality of *R. dominica* adults at 500, 1000 and 1500 ppm were achieved at 540, 360 and 270 min, respectively, at 12.40% moisture content (w.b.) of grains. Complete mortality of *R. dominica* adults placed in paddy grains at 14.20% moisture content (w.b.) was achieved at an exposure time of 610, 390 and 300 min when treated at the same concentrations (Table 2).

The moisture content of ozone treated grains decreased upon storage. The moisture content of grains initially at 12.40% (w.b.) was found to reduce to 12.06, 11.66 and 11.46 per cent on the 60th day when ozone gas was used at 500, 1000 and 1500 ppm, respectively. Similarly, the moisture content of grains initially at 14.20% (w.b.) was found to reduce to 13.82, 13.20 and 13.05 per cent, respectively, when ozone gas was used at the same concentrations (Fig. 2).

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