

Research Article

Optimalization of Temperature to Control *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae) on Nutmeg

Optimalisasi Suhu Udara untuk Pengendalian *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae) pada Biji Pala

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ABSTRACT

The exported nutmeg of Indonesia is frequently affected by the coffee bean weevil, *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae), so that it should be fumigated prior to export. CH₃Br is an effective fumigant used as quarantine measure for export products for 24 h, but this fumigant has been prohibited. Therefore, air temperature treatment is one of the alternative strategies. This research was aimed to determine the optimum air temperature in controlling *A. fasciculatus* on nutmeg. Healthy nutmeg, infected and *A. fasciculatus*-containing nutmeg, as well as individual adults of *A. fasciculatus* were treated with air temperature of 30–70°C for 1–24 h. The optimum air temperature was the lowest temperature which could kill 100% of examined insects. The results showed that 100% mortality of *A. fasciculatus* adults outside nutmeg occurred at air temperature of 45°C for 12 h or 50°C for 6 h. Meanwhile, 100% mortality of life stadium of *A. fasciculatus* inside nutmeg happened at air temperature of 55°C for 24 h. The raising of air temperature at 30–50°C for 24 h decreased the water content of nutmeg from 5.59±0.25 to 3.79±0.24%. The increment of temperature from 50 to 55°C for 24 h reduced the weight of nutmeg from 5.20±0.72 to 5.04±0.70 g. Air temperature treatment at 45–50°C for 12–24 h could eliminate adults of *A. fasciculatus* on exported nutmeg and air temperature of 55°C for 24 h could remove all life stadia of *A. fasciculatus* within nutmeg.

Keywords: *Araecerus fasciculatus*, coffee bean weevil, control, nutmeg, quarantine, temperature treatment

INTISARI

Biji pala ekspor Indonesia sering diserang oleh kumbang bubuk biji kopi, *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae), sehingga harus difumigasi sebelum diekspor. Tindakan karantina pada produk ekspor yang sering menggunakan CH₃Br efektif selama 24 jam, namun fumigan ini sudah dilarang. Oleh karena itu, perlakuan suhu udara merupakan salah satu alternatifnya. Penelitian ini bertujuan untuk menentukan suhu udara optimal untuk mengendalikan *A. fasciculatus* pada biji pala. Biji pala yang sehat, biji pala yang terserang dan berisi serangga *A. fasciculatus* serta imago *A. fasciculatus* diperlakukan dengan suhu udara 30–70°C selama 1–24 jam. Suhu udara optimal yaitu suhu terendah yang dapat membunuh 100% serangga uji. Hasil penelitian menunjukkan bahwa 100% mortalitas imago *A. fasciculatus* di luar biji pala terjadi pada suhu udara 45°C selama 12 jam atau 50°C selama 6 jam. Sementara itu, mortalitas 100% stadia hidup *A. fasciculatus* di dalam biji pala terjadi pada suhu udara 55°C selama 24 jam. Kenaikan suhu udara 30–50°C selama 24 jam menurunkan kadar air biji pala dari 5,59±0,25 menjadi 3,79±0,24%. Peningkatan suhu dari 50 menjadi 55°C selama 24 jam menurunkan berat biji pala dari 5,20±0,72 menjadi 5,04±0,70 g. Perlakuan suhu udara 45–50°C selama 12–24 jam dapat mengeliminasi imago *A. fasciculatus* pada biji pala ekspor dan suhu udara 55°C selama 24 jam dapat mengeliminasi semua stadia hidup *A. fasciculatus* di dalam biji pala.

Kata kunci: *Araecerus fasciculatus*, biji pala, karantina, kumbang biji kopi, pengendalian, perlakuan suhu

INTRODUCTION

The trade of agricultural commodities amongst countries through exports and imports may magnify the risks of importing and distributing the insect pests and quarantine insect pests. Postharvest products could easily become hosts of the pests. Nutmeg (*Myristica fragrans* Houtt) is a spice plant and its seed is an export commodity of Indonesia. The nutmeg seeds in the warehouse, including those to be exported, are often attacked by the coffee bean weevil, namely *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae) (Siswanto, 1987). The impact of its attacks decreased the quality of nutmeg seeds. The magnitude of losses due to *A. fasciculatus* attack on nutmeg seeds is not widely known, but in cassava products it is reported to cause a decrease in weight to 91.51% after 3 months of storage (Salomon, 2002).

The export nutmeg seeds must meet health, safety, and environmental protection standards. The provisions of the World Trade Organization (WTO) on Sanitary and Phytosanitary Measures (SPS) specifically state that each country should be responsible for securing itself from imported products that do not meet the established standards such as pests, diseases and disease-carrying organisms from the region of origin (Fakhrudin, 2008).

One attempt to prevent the entry, spread of harmful pests from one region to another or from one country to another is by a quarantine regulation under Act No. 16 of 1992. Quarantine measures are, among others, by fumigation treatments. Fumigation is one way conventional phytosanitary to eliminate 100% warehouse pest. Methyl bromide (CH_3Br), hydrogen phosphide, and sulfuryl flourid fumigants although they may be degraded but residues remain detectable on fumigated products (Sulaiman *et al.*, 2011). Concerns about health and environmental pollution, causing the need for alternative environmentally friendly control techniques. Cold treatment (Gould & Hennesey, 1997), heat treatment and UV irradiation are non-chemical methods that can kill pathogens on the surface of commodities, and are environmentally friendly (Mitcham, 1999; Mari *et al.*, 2009). Some heat treatments that can be used include hot water treatment, vapor heat treatment, and hot air treatment (Lurie, 1998; Shellie & Mangan, 2000). Hot air treatment has long been used for the quarantine measures (Gaffney & Armstrong, 1990).

Quarantine action to eliminate 100% warehouse pest with fumigation using CH_3Br is conducted for 24 hours. Currently the CH_3Br fumigants are prohibited for use because residual impacts are harmful to health and can also damage the ozone layer (Rohaeti *et al.*, 2010). Breakthrough effective control techniques, safe, environmentally friendly, and fast must be sought. One alternative control technique is the treatment of hot air temperature. This study aims to determine the optimal air temperature applied within 24 hours to eliminate the *A. fasciculatus* attack on export quality of nutmeg seeds.

MATERIALS AND METHODS

This research was conducted from October 2016 until February 2017 at Class I Agricultural Quarantine Center Laboratory in Manado. The *A. fasciculatus* adults were obtained from the exporter's nutmeg warehouse. The morphology of this weevil specimens is matched to the morphological characteristics in Haines (1991) to ascertain the originality of the species. The test insect was F1 generation of mass rearing of *A. fasciculatus* on nutmeg seeds in wooden box measuring $30 \times 30 \times 30 \text{ cm}^3$.

The nutmeg seeds without shell used in this study were of two kinds (Figure 1). The first was healthy nutmeg seeds of export quality. The kernels are intact, dense and filled, the surface of the seed is smooth enough, beeps when both kernels are knocked on each other, not infested by pests, not moldy, and not cracked (SNI 0006, 2015). The use of healthy nutmeg was intended to determine the effect of temperature treatment on water content. The second was the nutmeg seeds damaged by the infestation of *A. fasciculatus* during storage of 4 months. In the seeds there were larvae, pupae, and adult stages of the weevil. The use of attacked nutmeg was intended to determine the effect of temperature treatment on mortality of the weevil inside the nutmeg seeds.

The heat-generating device used is a heater that was connected to the thermostart panel as a digital temperature controller to control the temperature in the heating chamber. The heater was placed in the space heater of the box size $1 \times 1 \times 1 \text{ m}^3$ made of plywood with a thickness of 12 mm (Figure 2).

The heater was placed in the space heater of the box size $1 \times 1 \times 1 \text{ m}^3$ made of plywood with a thickness of 12 mm. The procedure to activate the heater

is as follows: the socket on the control panel was connected to the electric current, switch ON position, the temperature indicator light on the control panel will be on, indicating that the electric current had been connected to the heater to release hot air in the room. The indicator light turns off automatically when the temperature inside the heating chamber had reached at a set temperature and the electric current to the heater would be interrupted so that the heat flow through the heater stopped. If the temperature inside the heating chamber was below the prescribed temperature, the control panel automatically activated the electric current to the heater and the indicator light returns to ON.

Placement of nutmeg seeds and test weevils in the heating chamber is as follows: healthy nutmeg and infested nutmeg seeds by *A. fasciculatus* were prepared in as many as 30 seeds, respectively. Every bunch of 10 seeds was placed in a plastic bowl with diameter of 9 and height of 6.5 cm. All the bowls were covered with gauze. As many as 30 individuals adults of *A. fasciculatus* were treated, in which every 10 individuals was inserted into a bowl containing the seeds of healthy nutmeg. The bowls were neatly arranged in a heating chamber and treated with a set temperature

of 35, 40, 45 and 50°C, over a period of time of 1, 3, 6, 12, 18, and 24 hours. Temperature 30°C served as control because the outdoor air temperature of the treatment room was about 30°C, therefore the heater was not activated. During the heat treatment process the air temperature in the treatment chamber was manually recorded, to determine the range and average temperature during the exposure period (Table 1).

Measurement of moisture content of nutmeg seed using a moisture meter (Aqua Boy™), done before and after treatment. Therefore, the main observational variable was the mortality of the test weevil either outside the seeds or inside the seeds. Another variable was the decrease in water content of nutmeg seeds as a result of temperature treatment. The decrease of water content of nutmeg seeds was calculated by the formula:

$$KA = \frac{K0 - K1}{K0} \times 100\%$$

Where :

KA = Decrease in the amount of water content.

K0 = Water content before the temperature treatment.

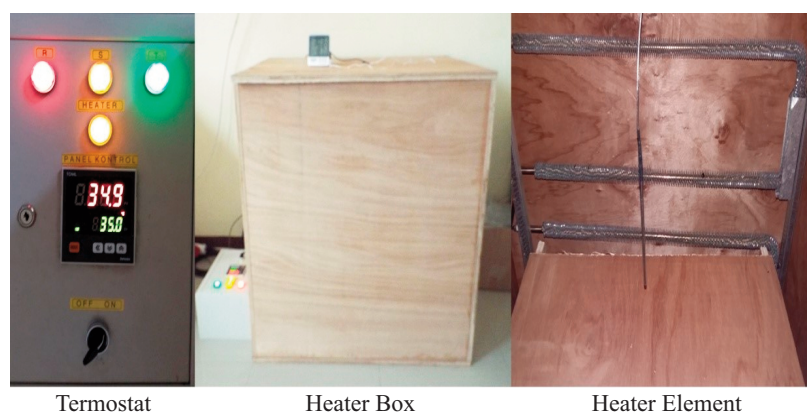
K1 = Water content after temperature treatment



The healthy nutmeg seeds

The damaged nutmeg seeds

Figure 1. The kinds of test nutmeg seeds



Termostat

Heater Box

Heater Element

Figure 2. The air equipment-heater

Table 1. Average temperature on treatment chamber during the exposure

| Exposure duration (hours) | Statistics | Air temperature inside the treatment box on temperature of (°C) | | | | |
|---------------------------|------------|---|-----------|-----------|-----------|-----------|
| | | 30 | 35 | 40 | 45 | 50 |
| 1 | n | 5 | 5 | 8 | 6 | 6 |
| | Range | 25.6–33.4 | 34.5–36.1 | 39.6–40.9 | 44.5–46.6 | 49.5–50.7 |
| | Average | 29.5±0.2 | 35.3±0.6 | 40.2±0.4 | 45.8±0.8 | 50.3±0.6 |
| 3 | n | 6 | 6 | 16 | 13 | 6 |
| | Range | 28.5–30.8 | 34.9–35.8 | 39.1–40.9 | 44.9–45.9 | 49.4–50.9 |
| | Average | 29.7±1.0 | 35.3±0.3 | 40.1±0.5 | 45.3±0.3 | 50.1±0.5 |
| 6 | n | 11 | 11 | 15 | 13 | 13 |
| | Range | 27.1–31.6 | 34.6–36.3 | 39.3–41.3 | 44.9–46.1 | 49.5–51.8 |
| | Average | 29.2±1.5 | 35.4±0.5 | 40.3±0.6 | 45.4±0.4 | 50.6±0.7 |
| 12 | n | 13 | 50 | 37 | 34 | 37 |
| | Range | 26.5–31.7 | 34.2–36 | 38.8–41.5 | 44–46.4 | 49.5–52.3 |
| | Average | 28.9±2.2 | 35.3±0.5 | 40.4±0.8 | 45.3±0.7 | 51.0±0.8 |
| 18 | n | 38 | 38 | 72 | 36 | 50 |
| | Range | 26.1–32.5 | 34.1–36.5 | 39–41.9 | 44.4–46.5 | 49.1–51.9 |
| | Average | 30.1±1.8 | 35.4±0.6 | 40.4±0.7 | 45.5±0.7 | 50.4±0.7 |
| 24 | n | 26 | 86 | 64 | 70 | 111 |
| | Range | 24.6–32.4 | 34.2–36.8 | 39–41.3 | 44.5–46.5 | 48.9–51.6 |
| | Average | 28.5±2.6 | 35.4±0.6 | 40.3±0.5 | 45.3±0.4 | 50.3±0.6 |

The optimal temperature for killing 100% of the test weevil in the desired time period was determined by connecting the temperature column and the exposure line in the matrix. Analysis of variance (ANOVA) and DMRT $\alpha_{0,05}$ was applied to determine the effect of temperature treatment on nutmeg seed moisture content.

RESULTS AND DISCUSSION

The Elimination of Adult A. fasciculatus Outside of the Nutmeg Seeds

At 35°C air temperatures the *A. fasciculatus* still survived, mortality began at 40°C. Increased mortality occurred at 45°C for 1 hour after treatment and all weevil died within 12 hours after exposure (Table 2). Adults of *A. fasciculatus* quickly died if the temperature was raised to 50°C, in just 6 hours all weevils were dead.

The response of most insect pests in storage at 35–45°C is showed by the ceased population growth and the move of the insects to find a cooler place. The insect pests are inactive at temperatures above the optimum temperature (estivation) usually starting from a temperature of 38°C to 45°C. Deaths of less than 1 day occur at temperatures of 45–50°C. The insect pest mortality at less than 1 hour occurs at temperatures of 50–62°C, and high temperatures more than 62°C can cause pest mortality in less than

1 minute (Field, 1992). At extreme temperatures of less than 15°C and 35°C, the *A. fasciculatus* eggs could not hatch. The threshold temperature of egg development is 12.2°C, larvae 12.2°C and pupa 11.7°C (Npumech & Ngozi, 1993). The optimum temperature for the reproduction of *A. fasciculatus* is 25–30°C (Salomon, 2002). Prolonging the temperature period below or above the optimum temperature can degrade the population of most pests (Wagiman, 2014). This study showed that the mortality of test weevil was positively and strongly correlated, $r = 0.9095$, with the duration of exposure. The temperature to kill the fastest total test weevil was 45°C for 12 hours or 50°C for 6 hours. The temperature treatment of 45–50°C has met the quarantine treatment criteria, in which a treatment should be able to give a 100% mortality effect on the pest. Rachman *et al.* (2015), stated that quarantine treatment should be able to completely kill pests resulting in zero tolerant measure. The implications of the results of the study in practice is that, to eliminate infestation of *A. fasciculatus* on nutmeg seeds, this commodity can be treated with hot air 45–50°C for at least 12 and 24 hours at the most. Rahmania (2017) stated that the high effective temperature for killing pests in the storage area is about 50–60°C for 24 hours. Ninety nine percent mortality of several species of coleopteran and psocopteran occurs at a temperature of 50°C after 2.5 hours of exposure (Beckett, 2011).

Table 2. Mortality of *Araecerus fasciculatus* beetle outside of nutmeg seed on several temperature treatment and exposure

| Air temperature | Mortality (%) of <i>A. fasciculatus</i> adults at exposure time for: | | | | | | Average |
|-----------------|--|--------|--------|---------|---------|---------|---------|
| | 1 hour | 3 hour | 6 hour | 12 hour | 18 hour | 24 hour | |
| 30°C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0,00b |
| 35°C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0,00b |
| 40°C | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 53.33 | 8,89b |
| 45°C | 3.33 | 40.00 | 63.33 | 100.00 | 100.00 | 100.00 | 67,78a |
| 50°C | 23.33 | 70.00 | 100.00 | 100.00 | 100.00 | 100.00 | 82,22a |

Remark: Average number following the different letter on the same column showed significance different according to Duncan's Multiple Range Test 5%.

*Data was transformed on $\sin^{-1}\sqrt{X + 10}$

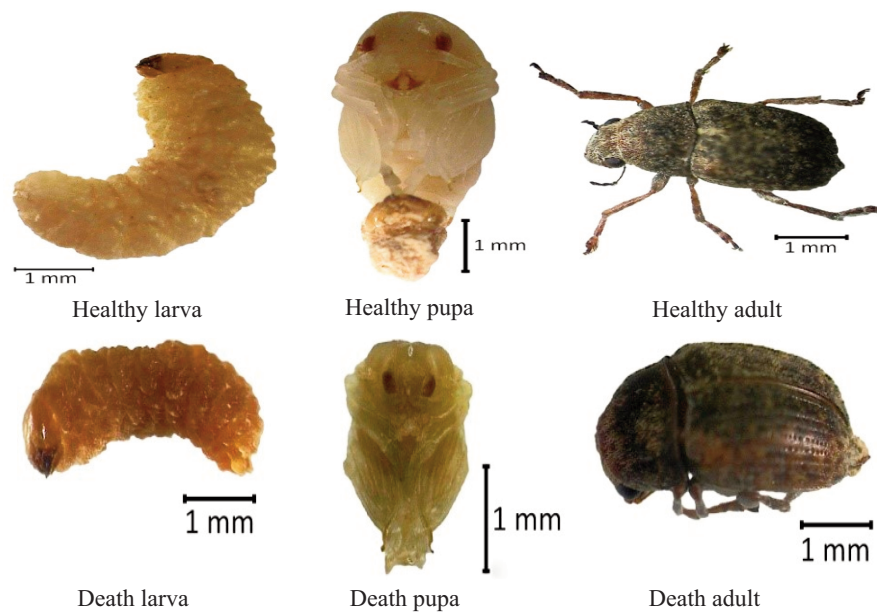


Figure 3. Healthy and death stages of *Araecerus fasciculatus* on before and after heat treatment

The Elimination of All Stages of A. fasciculatus Inside of the Nutmeg Seeds

From 30 seeds of the tested nutmeg seeds infested by *A. fasciculatus*, it was only 7–30% contained the individuals of the weevil, in as many as 1–2 larvae, pupa, or adults. At a temperature of 30–45°C for 24 hours, all stages of the weevil can survive and no one died. The number of live and dead weevil are illustrated with Figure 3.

This infested nutmeg seed test does not include the export quality seeds, but if it turns out that there is a possibility of being included in the trading system, it will be a source of pests infestation that must be eradicated. Mortality began to occur at 50°C for 18 hours at 9.09% and within 24 hours of 15.38% (Table 3). Therefore, by treating the air temperature of 50°C for 24 hours the mortality of *A. fasciculatus* had not reached 100% then it had not yet the criteria as the quarantine treatment, whereas a treatment

should be able to give 100% mortality effect on the pest (Rachman *et al.*, 2015).

The low mortality of test weevil inside seeds is thought to be due to temperatures in the seeds was not as yet deadly to *A. fasciculatus*. Grains have low temperature conductivity properties (Wagiman, 2014) so that 24 hours hot air exposure treatment had not increased the lethal temperature in the seeds. To increase the temperature at the core of the coffee beans from 26°C to 45°C hot air was applied at a temperature of 48°C for 237 minutes (Pan *et al.*, 2012). Increased temperatures inside the seeds, will increase the rate of respiration of pests in the seed so that O₂ levels in the seeds thinning and CO₂ levels in the seeds increased resulting in death in pests (Parjito, 2007). Drying of cashew seeds in Borma at a temperature of 70–85°C for more than 2 hours is effective for controlling infected grain seeds (Prabhakumary & Sivadasan, 2011).

Table 3. Number of infested nutmeg seeds and mortality of *Araecerus fasciculatus* inside the seeds

| Air Temp (°C) | Variables | <i>A. fasciculatus</i> at exposure time of (hours) | | | | | |
|------------------|----------------|--|-----------|-----------|-----------|-----------|-----------|
| | | 1 | 3 | 6 | 12 | 18 | 24 |
| 30 | Treated seeds | 30 | 30 | 30 | 30 | 30 | 30 |
| | Infested seeds | 7 | 9 | 9 | 9 | 6 | 10 |
| | Total insects | 8 | 10 | 10 | 10 | 6 | 11 |
| | Insec stages | 5L3P | 1L9P | 8L1P | 10L | 5L1P | 10L1P |
| | Range/seed | 1-2 | 1-2 | 1-2 | 1-2 | 1 | 1-2 |
| | Insects/seed | 1.14±0.38 | 1.11±0,38 | 1.11±0,38 | 1.11±0,38 | 1.00±0.00 | 1.10±0.32 |
| | Mortality (%) | 0 | 0 | 0 | 0 | 0 | 0 |
| | 35 | Treated seeds | 30 | 30 | 30 | 30 | 30 |
| Infested seeds | | 9 | 3 | 5 | 13 | 8 | 5 |
| Total insects | | 10 | 3 | 6 | 16 | 9 | 5 |
| Insec stages | | 7L3P | 3L | 4L2P | 11L3P2A | 7L2P | 4L1P |
| Range/seed | | 1-2 | 1 | 1-2 | 1-2 | 1-2 | 1 |
| Insects/seed | | 1.11±0,33 | 1.00±0.00 | 1.20±0.45 | 1.23±0.38 | 1.13±0.35 | 1.00±0.00 |
| Mortality (%) | | 0 | 0 | 0 | 0 | 0 | 0 |
| 40 | | Treated seeds | 30 | 30 | 30 | 30 | 30 |
| | Infested seeds | 6 | 4 | 7 | 10 | 9 | 9 |
| | Total insects | 8 | 5 | 8 | 11 | 11 | 11 |
| | Insec stages | 7L1P | 1L3P1A | 1L5P2A | 10L1P | 8L2P1A | 7L3P1A |
| | Range/seed | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 | 1-2 |
| | Insects/seed | 1.33±0.52 | 1.25±0.50 | 1.14±0.38 | 1.10±0.32 | 1.22±0.44 | 1.22±0.44 |
| | Mortality (%) | 0 | 0 | 0 | 0 | 0 | 0 |
| | 45 | Treated seeds | 30 | 30 | 30 | 30 | 30 |
| Infested seeds | | 5 | 5 | 13 | 10 | 5 | 4 |
| Total insects | | 6 | 5 | 15 | 12 | 5 | 5 |
| Insec stages | | 5L1P | 4L1P | 13L1P1A | 12L | 2L2P1A | 1L3P1A |
| Range/seed | | 1-2 | 1 | 1-2 | 1-3 | 1 | 1-2 |
| Insects/seed | | 1.20±0.45 | 1.00±0.00 | 1,15±0,38 | 1.20±0,42 | 1.00±0.00 | 1.25±0.50 |
| Mortality (%) | | 0 | 0 | 0 | 0 | 0 | 0 |
| 50 | | Treated seeds | 30 | 30 | 30 | 30 | 30 |
| | Infested seeds | 10 | 2 | 4 | 8 | 9 | 11 |
| | Total insects | 11 | 2 | 4 | 9 | 11 | 13 |
| | Insec stages | 10L1P | 1P1L | 3P1A | 9L | 9L1P1A | 9L4P |
| | Range/seed | 1-2 | 1 | 1 | 1-2 | 1-2 | 1-2 |
| | Insects/seed | 1.10±0.32 | 1.00±0.00 | 1.00±0.00 | 1.13±0.35 | 1.22±0.44 | 1.18±0.40 |
| | Mortality (%) | 0 | 0 | 0 | 0 | 9.09 | 15.38 |

Remark: L = larva, P = pupa, A = adult

Based on the results of probit analysis to kill 50% *A. fasciculatus* inside nutmeg seed for 24 hours, the required temperature is 58°C. Therefore a further study was done by increasing the treatment temperature from 55–70°C for 24 hours to determine the temperature range within the seed to eliminate the pest. The results of the study showed that an increase in temperature from 50°C to 55°C with 24 hours of exposure time was able to eradicate 100% of *A. fasciculatus* inside the nutmeg seed (Table 4).

All the temperature treatments show the temperature difference outside and inside the nutmeg seeds, whereas at the 55°C the temperature outside seeds

averaged 55.18°C and inside nutmeg seeds 45.02°C. Any increase in air temperature outside of the nutmeg seeds of 5°C will raise the temperature inside the seeds by an average of 2.02°C. The 24 hour time exposure within the temperature range is capable of eliminating 100% of *A. fasciculatus* in nutmeg. This is in line with Field (1992) which stated that pest deaths less than of 1 day occur at temperatures of 45–50°C. The increment of temperature from 50 to 55°C for 24 h reduced the weight of nutmeg from 5.20±0.72 to 5.04±0.70 g.

Temperature is one of the factors limiting the development of pests. Pests have a certain temperature

Table 4. Mortality of *Araecerus fasciculatus* inside the seed, weight seed decrease, temperature range of outside and inside nutmeg seed on several temperature for 24 hours

| Variables | | Temperatur treatment 24 h | | | |
|--|------------------|---------------------------|-----------|-----------|-----------|
| | | 55°C | 60°C | 65°C | 70°C |
| Mortality <i>A. fasciculatus</i> inside seed | Treated seeds | 30 | 30 | 30 | 30 |
| | Infested seeds | 21 | 12 | 15 | 19 |
| | Total insects | 33 | 15 | 17 | 25 |
| | Insec stages | 9L9P15A | 5L4P6A | 4L2P11A | 5L5P15A |
| | Range/seed | 1–2 | 1–2 | 1–2 | 1–2 |
| | Insects/seed | 1.57±0.51 | 1.25±0.45 | 1.13±0.35 | 1.31±0.48 |
| | Mortality (%) | 100.00 | 100.00 | 100.00 | 100.00 |
| Weight (g) of nutmeg seeds | Before treatment | 5.20±0.72 | 4.48±0.47 | 4.91±0.60 | 5.52±0.59 |
| | After treatment | 5.04±0.70 | 4.29±0.47 | 4.69±0.58 | 5.27±0.59 |
| | Decreament (%) | 0.17±0.05 | 0.19±0.05 | 0.22±0.08 | 0.25±0.05 |
| Air temperature inside box on temperature treatment | n | 22 | 22 | 22 | 22 |
| | Range | 54.9–55.7 | 59.9–60.3 | 64.9–65.5 | 69.9–70.6 |
| | Average | 55.18 | 60.01 | 65.02 | 70.02 |
| Air temperature inside seed on temperature treatment | n | 30 | 30 | 30 | 30 |
| | Range | 43.5–46.8 | 45.5–49.8 | 47.5–53.2 | 50.1–57.2 |
| | Average | 45.02 | 47.10 | 50.38 | 53.95 |

range to achieve maximum population growth. At low temperatures below the optimum temperature, the development and activity of pests is very slow, death is relatively high, causing low population growth rates to even reach zero or negative at extreme conditions. While at high temperatures above the optimum temperature, the rate of development, activity, and mortality of pests increased to 42°C, but the rate of population growth also decreased until no individual pest survived (Wagiman, 2014). Heat treatment above optimum temperature and prolonged period of exposure can kill almost all pest stages, so the existence of pest reinfestation after treatment can be minimized. The eggs that are able to hatch after treatment, their survivalship may be very small due to the lack of moisture content during the heating process.

Heat treatment at temperatures above 45°C is an effective quarantine treatment for control of fruit flies (Armstrong, 1992). Meanwhile, a study by Prabhakumary and Sivadasan (2011) found that a 75– 80°C temperature treatment for more or equal to 180 minutes (2 hours) could kill larvae, pupae, and adults of *Tribolium castaneum*. This is different from the chemical treatment (fumigant) which is a neurological and respiratory toxin, effectively kills pests in the active phases (larvae and adults), while eggs and pupa can still survive. When commodities are retained in the warehouse for a long time, for instance more than 21 days, the pest reinfestation

may occur, requiring refumigation to eliminate the existing pest reinfestation. This study with hot air treatment of 45–50°C for 24 hours *A. fasciculatus* on export quality nutmeg seeds can be considered so that further study should be needed to ensure need or not need to do the re-treated after the nutmeg seeds are stored for more than 21 days.

The Impact of Air Heat Treatment on the Moisture Content of Nutmeg Seeds

The criteria of quality of nutmeg seeds of Indonesian National Standard are as follows. The nutmeg seeds without shell, maximum water content of 10%, foreign object 0.5%, non moldy seeds, and no live or dead pest (SNI 0006, 2015). The treatment of air temperature and duration of exposure had significant effect on water content of nutmeg seeds. The higher the temperature and the duration of exposure, the moisture content of the nutmeg seeds decreases.

The air temperature treatment of 50°C for 24 hours decreased the moisture content of the nutmeg seeds from about 5.59±0.25 to 3.79±0.24%, the highest compared to the treatment temperature of 30, 35, 40, and 45°C (Table 5). The higher the applied temperature, the more water evaporates, and the lower the water content of the material (Fitriani, 2008).

The process of drying nutmeg seeds based on Permentan (Ministerial Decree) 53 Year 2012, is done through two stages at a temperature of less than 45°C. The first stage of drying the seeds of nutmeg

Table 5. Seed water content on several temperature treatment and exposure time before and after treatment

| Air Temp. | Variables | Water content (%) of nutmeg seeds at exposure time of | | | | | |
|-----------|-----------|---|----------------|-----------------|-----------------|-----------------|-----------------|
| | | 1 h. | 3 h. | 6 h. | 12 h. | 18 h. | 24 h. |
| 30°C | B. t. | 5.59±0.21 | 5.54±0.20 | 5.46±0.18 | 5.52±0.24 | 5.33±0.26 | 5.51±0.21 |
| | A. t. | 5.59±0.21 | 5.54±0.20 | 5.46±0.18 | 5.52±0.24 | 5.33±0.26 | 5.51±0.21 |
| | D. (%) | 0 e | 0 e | 0 e | 0 e | 0.12±0.65 e | 0.12±0.65 e |
| 35°C | B. t. | 5.63±0.18 | 5.64±0.21 | 5.65±0.18 | 5.32±0.22 | 5.29±0.20 | 5.58±0.15 |
| | A. t. | 5.27±0.13 | 5.17±0.15 | 5.03±0.10 | 4.57±0.10 | 4.44±0.07 | 4.63±0.10 |
| | D. (%) | 6.35±2.12 d | 8.15±2.9 d | 10.99±2.0 d | 13.91±2.2 d | 16.00±2.1 d | 17.06±1.3 d |
| 40°C | B. t. | 5.55±0.16 | 5.67±0.30 | 5.30±0.24 | 5.44±0.17 | 5.18±0.20 | 5.75±0.26 |
| | A. t. | 5.05±0.09 | 5.07±0.28 | 4.43±0.05 | 4.45±0.09 | 4.10±0.15 | 4.48±0.28 |
| | D. (%) | 8.84±2.22 c | 1.87±3.54 c | 16.23±3.16 c | 18.10±1.64 c | 20.93±1.90 c | 22.15±3.25 c |
| 45°C | B. t. | 5.70±0.20 | 5.45±0.22 | 5.40±0.16 | 5.56±0.25 | 5.93±0.23 | 5.29±0.32 |
| | A. t. | 4.99±0.11 | 4.53±0.17 | 4.27±0.09 | 4.31±0.12 | 4.52±0.18 | 3.83±0.14 |
| | D. (%) | 12.40±2.0 b | 16.77±4.3 b | 20.79±1.3 b | 22.30±2.2 b | 23.78±1.6 b | 27.53±3.8 b |
| 50°C | B. t. | 5.48±0.36 | 5.37±0.19 | 5.92±0.19 | 5.51±0.21 | 5.34±0.24 | 5.59±0.25 |
| | A. t. | 4.88±0.11 | 4.19±0.07 | 4.548±0.2 | 3.99±0.10 | 3.71±0.15 | 3.79±0.24 |
| | D. (%) | 16.17±3.9 a | 21.85±2.3 a | 23.36±2.0 a | 27.58±2.06 a | 30.47±1.84 a | 32.24±2.39 a |

Remark: B. t. = Before treatment, A. t. = After treatment, D. = Decrement. Average followed by the different letter within column shows significantly different, transformed data into $\sin^{-1} \sqrt{X + 10}$ and DMRT $\alpha_{0.05}$

in the shell in order to separate the seed from the shell and the second stage is done after nutmeg seed removed from the shell in order to decrease the seed water content reaches 10–12%. Use of a heater at a temperature treatment of 50°C for 24 hours of effective exposure to replace the second-stage drying process so that no repeated drying treatment occurs within a month before the nutmeg is exported. The treatment, in addition to lowering the moisture content of the nutmeg seeds, can also control *A. fasciculatus* (Table 2). Storage of nutmeg seeds with a low moisture content of less than 5% is thought to be more resistant to *A. fasciculatus* attack because the seeds become hard and the weevils are not able to obtain water to live from the seeds eaten. Also reducing the water content in the material can control the growth of other microorganisms. The treatment of hot air in soybean seeds with temperatures of 50–60°C can suppress the growth of four types of pathogenic fungi (Syahputra & Hadi, 2012; Situmeang *et al.*, 2014) and relatively not affect the quality of the shelf ingredients (Christin *et al.*, 2013). The treatment of hot air of 45–50°C for 24 hours was able to kill

total of adults of *A. fasciculatus* outside the nutmeg seeds. Meanwhile, to eliminate the total stages of the weevil pest within the seeds required air temperature of 55°C for 24 hours. Thus, the heat air treatment is effective and safe and expected to potentially replace the fumigation with CH₃Br.

CONCLUSION

The air temperature treatments of 45°C for 12 hours or 50°C for 6 hours were effectively to eliminate 100% of *A. fasciculatus* outside the nutmeg seeds, and of 55°C for 24 hours was effectively to eliminate 100% of all stages of *A. fasciculatus* inside the nutmeg seeds. The implications of the results of the study on a large scale, the distribution of the temperature should be uniform on all sides of the room for at least 12 and the longest at 24 h.

An increase in temperature from 30° to 50°C for 24 hours decreased the moisture content of the nutmeg seeds from 5.59±0.25 to 3.79±0.24%. The increment of temperature from 50 to 55°C for 24 h reduced the weight of nutmeg from 5.20±0.72 to 5.04±0.70 g.

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