Development and performance evaluation of aerator for thermal disinfestation of cowpea weevil (*Callosobruchus maculatus*)

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Abstract

The major problem of cowpea storage is destruction by insects during storage, studies have revealed that more than 30% of cowpea destroyed due to insect activities in storage facilities. Cowpea weevil (Callosobruchus maculatus) is the most common insect of the cowpea which has the potential of destroying up to 100% of cowpea seeds depending on storage duration and environmental conditions. Thermal aerator was designed for insects treatment on cowpea with a view to disinfest the cowpea weevil life cycle completely. The components of the aerator consist of heater, disinfestation chamber, plenum, distribution pipes and heat regulator were locally sourced. Tests evaluation was conducted, and the results showed that the aerator increased mean ambient temperature from 25.21°C to 59.79±1.04°C. Insects at all stages of development (egg, larva, pupae and adult) were observed to be completely destroyed when the hot air pushed into the disinfestation chamber at 59.79°C for 15minutes without any adverse effect on physical properties of the sample as against other methods which do not completely eradicate the insects while maintaining the quality of the produce. Sample were stored for more than 6 months, and the result agreed with the findings of other researchers that recommended 60°C heat treatment for 15 minutes is adequate to eliminate all stages of development of C. maculatus and to keep cowpea safe in storage facilities.

Keywords: *Cowpea weevil, storage insects, disinfestation and hot air aeration,*

Développement et évaluation des performances d’un aérateur pour la désinfestation thermique du charançon du niébé (*Callosobruchus maculatus*)

Résumé

Le problème majeur du stockage du niébé est la destruction par les insectes pendant le stockage, des études ont révélé que plus de 30% du niébé détruit en raison des activités des insectes dans les installations de stockage. Le charançon du niébé (Callosobruchus maculatus) est l’insecte le plus commun du niébé qui a le potentiel de détruire jusqu'à 100% des graines de niébé en fonction de la durée de stockage et des conditions environnementales. L'aérateur thermique a été conçu pour le traitement des insectes sur le niébé en vue de désinfecter complètement le cycle de vie du charançon du niébé. Les composants de l'aérateur se composent d'un réchauffeur, d’une chambre de désinfestation, d'un plénum, de tuyaux de distribution et d'un régulateur de chaleur d'origine locale. L’évaluation des tests a été menée et les résultats ont montré que l'aérateur augmentait la température ambiante moyenne de 25,21 oC à 59,79 ± 1,04°C. On a observé que les insectes à tous les stades de développement (œuf, larve, pupe et adulte) étaient complètement détruits lorsque l'air chaud était poussé dans la chambre de désinfestation à 59,79°C pendant 15 minutes sans aucun effet néfaste sur les propriétés physiques de l'échantillon, contrairement à d'autres méthodes qui ne pas éradiquer complètement les insectes tout en maintenant la qualité des produits. Les échantillons ont été stockés pendant plus de 6 mois, et le résultat concorde avec les conclusions d’autres chercheurs qui recommandent un traitement thermique à 60°C *pendant 15 minutes pour éliminer tous les stades de développement de C. maculatus et pour assurer la sécurité du niébé dans les installations de stockage.*

***Mots-clés** : Charançon du niébé, insectes de stockage, désinfestation et aération à air chaud*,

المشكلة الرئيسية لتخزين اللوبيا هي تدمير الحشرات أثناء التخزين وكشفت الدراسات السابقة أن أكثر من ثلاثين في مائة من
.اللوبيا دمرت بسبب أنشطة الحشرات في مرافق التخزين
٪ من بذور اللوبيا 100وكأنت سوسة اللوبيا هي الحشرة الأكثر شيوعًا في اللوبيا التي لديها القدرة على تدمير ما يصل إلى
وكانت الهواء الحراري هي الخطة المصممة لعلاج الحشرات في اللوبيا حيث تهدف ..حسب مدة التخزين والظروف البيئية
تتكون مكونات الهواء من سخان، ودائرة إزالة الحشرات، وكذالك تم الحصول ..نحو تطهير دورة حياة سوسة اللوبيا بالكامل
أجري تقييم للاختبارات فأظهرت النتائج أن الهواء زاد متوسط درجة .على أنابيب التوزيع ومنظم الحرارة من مصادر محلية
البيض واليرقات والشباب)والحشرات في جميع مراحل التطور .59.79±1.04oCإلى 25.21oCالحرارة المحيطة من
لمدة خمسة عشر دقيقة، دون 59.79oCلوحظ أنها دمرت بالكامل عندما اندفع الهواء الساخن إلى غرفة التطهير في (والبالغين
أي تأثير سلبي على الخصائص الفيزيائية للعينة مقارنة بالطرق الأخرى التي لا تقضي تماما على الحشرات مع الحفاظ على
60oCتم تخزين العينة لأكثر من ستة أشهر واتفقت النتيجة مع نتائج الباحثين الآخرين الذين أوصوا بأن .جودة المنتجات
والحفاظ على أمان اللوبيا C. maculatusالمعالجة الحرارية لمدة خمسة عشر دقيقة كاف للقضاء على جميع مراحل تطور
.في مرافق التخزين

Introduction

Grain storage is a unit operation in postharvest handling of agricultural produce to elongate the shelf stability of food produce along processing chain without appreciable lost in values (Ofuya, 1989; Ohanwe and Sule, 2007). The importance of grain storage and other agricultural produce is very paramount to ensure food safety in postharvest handling. After crop harvesting, there is need for proper storage system to preserve the farm produce safe over a long period of time without any significant alteration in all characteristics (colour, taste, odour, size, moisture content, shape, volume and porosity) features of the produce (Ohanwe and Sule, 2007). Adequate handling of agricultural produce from the secondary processes required serious attention to avoid postharvest losses and ensure safety in the material handling of commodities at various stages of moisture extraction depending on the duration and system of the storage (Johnson and Valero, 2013).

Study revealed that most agricultural produce are always exposed to insect attack especially during the storage of pod produce (Ahmad *et al*., 2021). An estimate of such crop losses varies depending on whether they are based on temperate crops, where insects are relatively unimportant, or on tropical crops, where insects can be very damaging particularly to modern heavily fertilized high yielding (Singh and Emden, 1979)

Post-harvest losses, including processed foods in store, can be very severe and are compounded by the effect of insect on the quality and market value of food (Kumar and Kalita, 2017).

In Nigeria, especially Northern Nigeria where the environmental conditions favoured the growing of cowpea (beans), the most popular weevil include beans weevils (*Acanthoscelides obtectus*), cowpea weevils (*Callosobruchus maculatus*) and pea weevils *Bruchus pisorum.*

The seed weevils occasionally become pests of stored beans, cowpea and peas. Damage consists of complete or partial destruction of infested seeds by numerous round holes or destruction of all but the outer shell. The adult beetles usually succeed in laying eggs into cowpea pods before it grows to maturity, and remains inactive until conditions favoured hatching and enable them to reproduce and multiply. Many efforts including the use of oil and botanicals, hermetic storage, metal drum system, triple plastic bagging system, co-storage with ash, solar and other heating techniques and chemical control have been employed by the farmers to control the problem yet, none of the methods ascertain better result without adverse effects on either the stored cowpea or human being, complete disinfestation is nearly impossible due to enclosure of the eggs in the cotyledons of the pods however, heat can easily diffuse in to the pods and destroy the eggs. Therefore, it is very essential to evaluate the application of thermal aeration on cowpea for the prevention of insect manifestation on stored produce, a machine is developed to generate and aerate hot air into infested cowpea in order to destroy all insects at various level of growth. A cross section of a typical cowpea seed (Figure1) indicating its features as evaluated by Tarver *et al.,* (2005) would help to ascertain the various compartment where insect could exist in the sample.

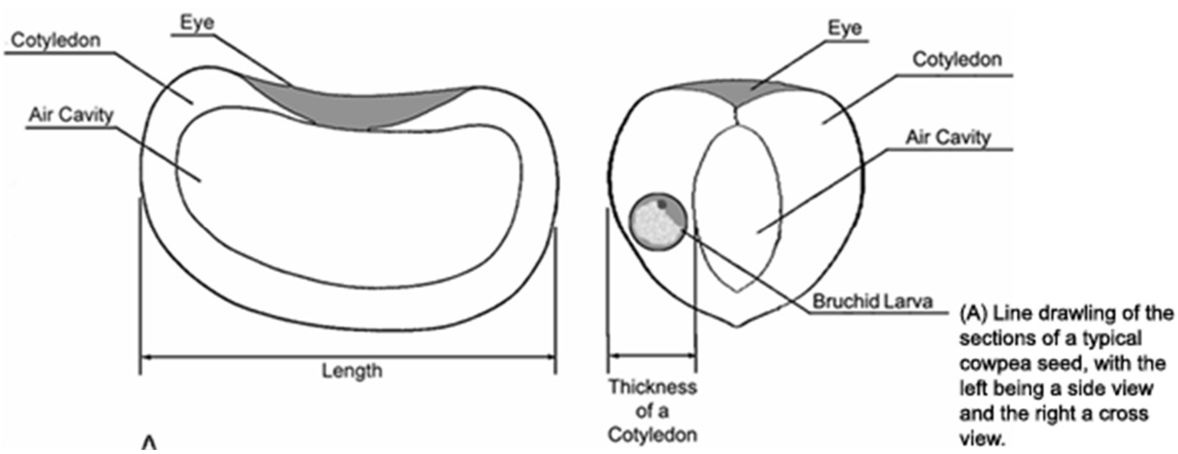


Figure 1: Cross section of typical cowpea seed with left being the side view and the right a cross view (Tarver *et al.,* 2005)

Materials and Methods

Design Consideration: The following were put into consideration in the design work; depth of the disinfestation chamber, capacity of the disinfestation chamber, depth of the plenum, compactness and availability of the construction materials.

Design Components: Disinfestation chamber, Distribution pipe, Plenum chamber and Blower

Design Calculations: The design calculation centered on the following.

Disinfestation Chamber: A cylindrical shape of disinfestation chamber was chosen to aerate 40 kg of cowpea, therefore dimension chosen are diameter is 40cm and depth to be 45cm. The volume of the disinfestation chamber (V) is
V=56548.70cm^3 as shown in figure 2

Perimeter of disinfestation chamber (P) is

$$p = 125.7cm$$

***Plenum Chamber*:** The depth of the plenum chamber is chosen to be 10cm and the diameter is the same as that of the disinfestation chamber
Perimeter of the plenum chamber
$p = 125.7cm$(+2cm for clearance)

***Distribution pipes*:** The function of distribution pipe is to help distribute air in the disinfestation chamber. It was perforated to ensure even distribution of heat. Diameter of 4cm and lenght of 45cm were used for the design
The perimetre is
$p = 12.60cm$

Blower Selection: A fan was selected based on pressure drop, density factors of the grain and

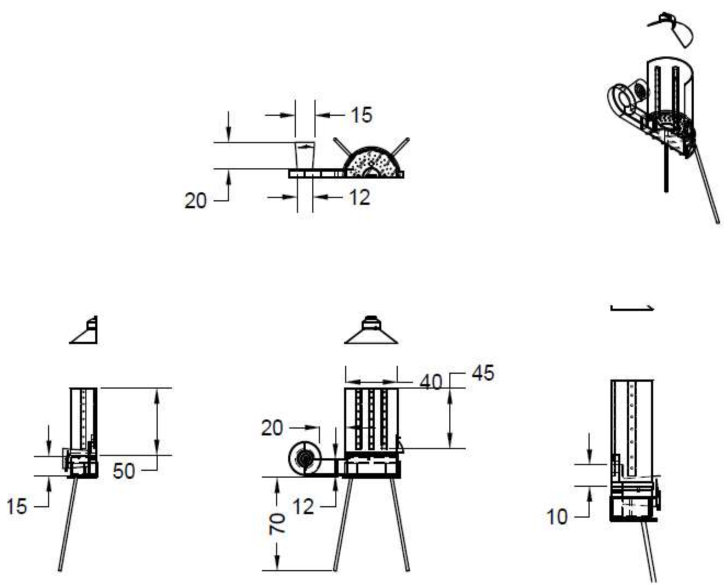


Figure2: Components and their dimensions

$\frac{Dp}{L} = aQ_v^b$, (Gunasekaran and Jackson, 1988) …(1)

Where:

D_p is the pressure drop (Pa/m)

L is the depth of the grain (m)

Q_v is the air flow velocity ($m^3/s-m^2$)

a and b are constant depends on the grain type

Constant value for cowpea were obtained from ASAE (1999) for the air flow velocity.

Q_v= 0.030-0304($m^3/s-m^2$)

a is 3.80×10^3(Pa. s^2/m^3)

b is 111.0($m^2.s/m^3$)

$Dp = 3.80 \times 10^3 0.304^{111} \times 0.45$

$Dp = 6.79 \times 10^{-55} pa/m$

The fan is selected best on the value calculated.

Machine Description

The following are the components of the aerator:

Distribution Pipes (air ducts): Four evenly perforated pipes with 4cm in diametre and 40cm

the depth of the grain to be aerated, equation 1 is used to obtain pressure drop.

height made of stainless steel sheet were fixed within the disinfestation chamber to receive hot air from the plenum and to evenly distribute the air in the chamber (figure 3)

Disinfestation Chamber: This is a 40cm diametre and 45cm depth made of stainless steel sheet capable of accommodating 40kg (*Vigna unguiculata*) of cowpea product (figure 3)

Plenum Chamber: This consist of 10cm depth and 40cm diametre made of stainless steel sheet where heat dissipated from the heating element is mixed with the air drown from ambient surrounding and push into the disinfestation chamber.

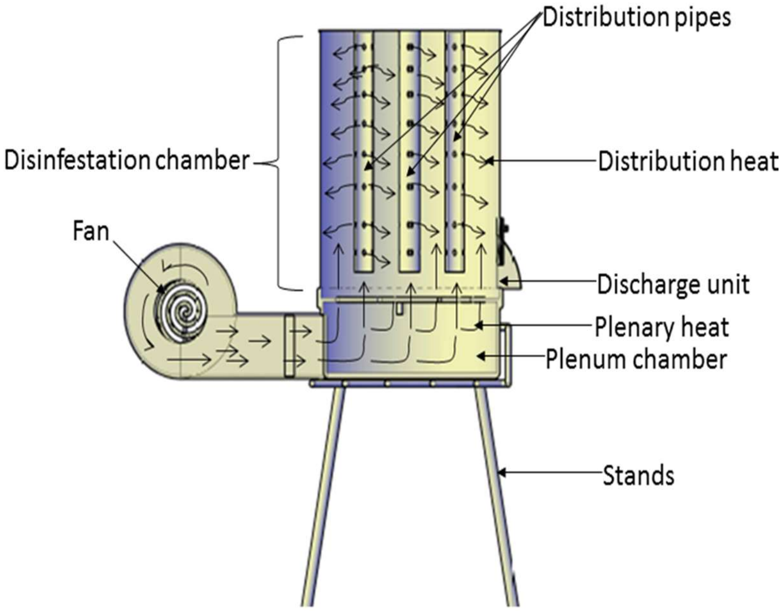
Blower: This is a 12 volt DC centrifugal air moving device for blowing air in to the disinfestation chamber, it has the capacity of blowing 300$m^3/s-m^2$

Heater: This is the heat generating device.

Machine frame: This is made of 12mm iron rod and 70cm long for supporting the machine, 40cm hollow pipe as a stand.

Operation Principle of the Machine

The various parts of the machine were coupled together and the disinfestation chamber was filled with the infested weevil, the heater was switch on and allowed to heat up, blower were also switch on and blew heatup air in to the disinfestation chamber through plenum and distribution chamber. The sample were allowed to be heated for 15 minutes at 59.79±1.04°C, after achieving the required time and circulation, the air exit through outlet on the cover of the disinfestation chamber.



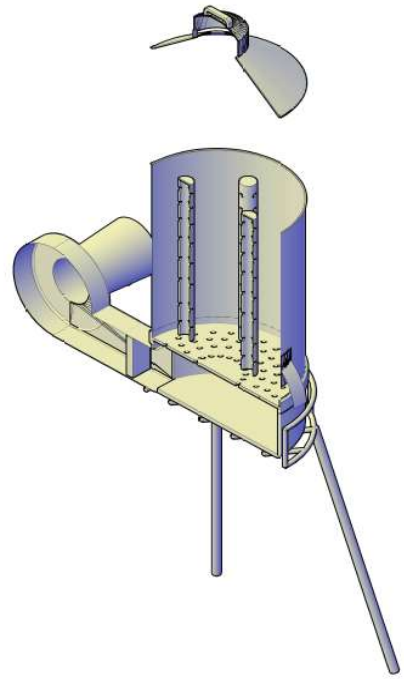


Figure 3: Components and thermal distribution pattern.

Figure 4: Cross section of the aerator

Machine Evaluation

The perfomance of the machine was evaluated on the basis of conveyance effciency, heat application efficiency and ambient air condition influence. All data obtained were in triplicate and were statistically analysed.

Figure5: picturial views of of the aerator

Conveyance Effeciency

$E_C = \frac{H_2}{H_1} \times 100$ …(2)

Where:

$E_c = Conveyance\ Efficiency$ (%)

$H_2 =$
$Mean\ Temperature\ at\ the\ begining\ of\ conveyance$
(°C)

$H_1 =$
$Mean\ Temperature\ entering\ disinfestation\ chamber$
(°C)

Application Effeciency

$A_C = \frac{T_2}{T_1} \times 100$ …(3)

Where:

$A_c = Application\ Efficiency$ (%)

$T_2 =$
$Mean\ temperature\ at\ diffrent\ depth$ (°C)

$T_1 =$
$Mean\ temperature\ entering\ disinfestation\ chamber$
(°C)

Results And Discussions

The results of evaluation test were presented in Table 1- 4

Table1: Heat loss during conveyance

Days	Test	Heat generated (H_1) °C	Heat entering the chamber (H_2) °C	Environmental temperature °C (10.00am)	Environmental temperature °C (3.00pm)
07/01/2018`	1	63.81	60.22	22.20	28.31
08/01/2018	2	62.99	60.04	21.55	27.00
09/01/2018	3	61.00	59.79	22.67	29.48
	Average	62.60	60.02	22.14	28.26

Table2: Average temperature at different depth in disinfestation chamber

	Temperature °C			
Test time	10cm dept	20cm depth	30cm depth	40cm depth
8:00 am	58.30	60.30	59.67	61.00
10:00 am	60.00	59.67	61.00	59.33
12:00 pm	59.33	60.33	60.67	60.67
2:00 pm	61.00	58.67	58.33	61.00
4:00 pm	61.33	60.00	59.00	61.00
6:00 pm	58.00	59.00	58.67	58.67
Average	59.66±1.37	59.66±0.69	59.56±1.09	60.28±1.02

Table 3: Percentage temperature increased

Test	Average daily ambient temperature(°C)	Average increased temperature(°C)	%Temperature increase
1	25.26	59.66	34.40
2	24.28	59.66	35.38
3	26.08	59.56	33.48
4	25.21	60.28	35.07

Table 4: Properties of ambient air before aeration

Time	Temperature °C		Relative humidity (%)	Enthalpy (kJ/kg) of dry air	Saturation vapour pressure (mm) of mercury	Humidity ratio(g) of moisture per kg of dry air	Specific volume (m^3) per kg of dry air
	Dry bulb	Wet bulb					
8:00am	21.40	8.90	12.70	26.60	25.40	2.00	0.836
10:00am	22.20	9.10	11.20	27.03	26.77	1.85	0.840
12:00pm	28.30	11.70	7.50	33.03	38.50	1.80	0.856
2:00pm	29.40	11.90	6.00	33.54	41.02	1.56	0.858
4:00pm	28.60	11.40	5.80	32.31	39.16	1.39	0.856
6:00pm	26.40	10.30	5.90	29.76	34.44	1.26	0.849
Average	26.05	10.55	8.18	30.38	34.22	1.64	0.849

Discussion

From Table 1, the result shows that the mean difference between the heat generated and the heat received in the disinfestation chamber was 2.58°C which indicate 95.88°C heat temperature conveyance efficiency. From Table 2, the result shows that there is no significant difference of heat distribution at different depth in the disinfestation chamber (i.e. 10, 20, 30 and 40) cm depth at different time interval

From Table 3, it was observed that there is no influence of the ambient temperature changes on the performance of the machine. Despite change of ambient temperature from 22.14°C to 28.26°C, the heat supplied remained the same.

From Table 4, the following are properties of ambient air used: Dry bulb temperature (26.05°C), Wet bulb temperature (10.55°C), Relative humidity (8.18%), Enthalpy of dry air (30.38kJ/kg), Saturation vapour pressure of mercury (34.22mm), Humidity ratio of moisture (1.64g/kg) and Specific volume (0.849m^3/kg)

The characteristics of the product used in the performance evaluation of the machine may significantly affect the machine efficiency however; the product used is cowpea (*Vigna sinensis l.*) with the following physical properties: Bulk density (723.14kg/m^3), Porosity(40.28%), Moisture content(12.39%), Specific density (0.393cm^3), Average length (12.20mm), Average width (7.83mm) and Average thickness (6.02mm).

The temperature of the disinfestation chamber was taken at different depth to ascertain the uniformity of heat distribution in the chamber, the average temperature of the disinfestation chamber is 59.79±1.04 and that in literature is 60°C (shade, *et al.,* 2002) The ambient temperature recorded shows no effect on the performance of the machine.

After the performance evaluation of the machine and the disinfestation, the cowpea was kept under close supervision for a period of 29 weeks (7 months) from January to August, the average ambient temperature and relative humidity were 30.11ºC and 44.18% respectively during the storage period. Lale and Vadal (2003) reported the temperature between 17.5 to 35ºC and relative humidity 30 to 90% favour the population growth of *C. maculatus*.

Conclusion

A simple efficient and less tedious machine has been design and developed using locally available materials to heat up and convey ambient air to the disinfestation chamber with the heat generation of 60.28ºC efficiency of up tp 95.88% to terminate all development stages (egg, larva, pupa and adult) of cowpea weevil (*C. maculatus*) growth within 15 minutes. The machine has the capacity of disinfesting 40.90kg/hr of cowpea seeds and it can help to substantially reduce the postharvest losses due to insects destructive activities in storage.

References

Ahmad, R., Hassan, S., Ahmad, S., Nighat, S., K. Devi, Y., Javeed, K., Hussain, B. (2022). Stored grain pests and current advances for their management. postharvest technology - recent advances, New Perspectives and Applications: *IntechOpen Journals.*

American Society of Agricultural Engineers (ASAE). *Standards Engineering Practices Data*, 46th Edition (1999)

Gunasekaran, S. and Jackson, C. Y. (1988). Resistance to Airflow of Grain Sorghum: *American Society of Agricultural Enginers (ASAE):* 31(4): 1237

Johnson, J. A. and Valero, K. A. (2013). Use of commercial freezers to control cowpea weevil, Callosobruchus maculatus. *Journal of Economic Entomology.*, 9(6): 1952-1957.

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*. 6(1): 2-22, 8.doi:10.3390/foods6010008 10.3390/foods6010008

Lale, N. E. S. and Vidal, S. (2003). Effect of constant temperature and humidity on oviposition
and development of Callosobruchus maculatus (F.) and Callosobruchus subinnotatus (Pic) on bambara groundnut, Vigna subterranea (L.) Verdcourt. *Journal of Stored Products Research*., 39(5): 459-470

Ofuya, T. I. (1989). The effect of pod growth stages in cowpea on aphid reproduction and damage by the cowpea aphid, (*Aphis craccivora*). *Journal of annals of applied biology*, 115(3): 546-566

Ohanwe C. N. and Sule S. (2007). Fundamentals of Grain Draying and Storage. *Bauchi PalmGate Ptinting and Publishing Company*.1(8):68-90.

Shade L. G, Opara A. V., Terry E. R, and Doke E. V. (2002). Identification and Control of Insects in the Envitoment. *Journal of Food and Agriculture*, 33(12): 501-512.

Singh S. R., and Emden H. F. V.(1979). Insect Pests of Grain Legumes.*Annual Review of Entomology*, 24:255-278

Tarver, M. R., Shade, R. E., Tarver, R. D., Liang, Y., Krishnamurthi, G., Pittendrigh, B. R. and Murdock, L. L. (2005). Use of Micro-CAT scans to understand cowpea seed resistance to *Callosobruchus maculatus*