

Application of microwave and radio frequency energy to control *Sitophilus zeamais* (Coleoptera: Curculionidae) in maize grains

Dissertation

to obtain the Ph.D. degree

in the International Ph.D. Program for Agricultural Sciences in Göttingen
(IPAG)

at the Faculty of Agricultural Sciences,
Georg-August-University Göttingen, Germany

Presented by

Amro Babiker Hassan Eltayeb

Born in Khartoum, Sudan

Göttingen, July 2012

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Babiker, Amro:

Application of microwave and radio frequency energy to control *Sitophilus zeamais* (Coleoptera: Curculionidae) in maize grains

ISBN 978-3-86376-025-0

D7

1. Referee: Professor Dr. Wolfgang Lücke

2. Co- referee: Professor Dr. Elke Pawelzik

Date of dissertation: 16th July 2012

Printed with support from the German Academic Exchange Service (DAAD)

All Rights Reserved

1. Edition 2012, Göttingen

© Optimus Verlag

URL: www.optimus-verlag.de

Printed in Germany

Paper is FSC certified (wood-free, chlorine free and acid-free,
and resistant to aging ANSI 3948 and ISO 9706)

No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, scanning, or otherwise without the prior written permission of the Publisher. Request to the Publisher for permission should be addressed to info@optimus-verlag.de.

To my Parents

Sisters

Wife and son

I dedicate this work

with love

Acknowledgement

First of all, I would like to express my deepest sense of gratitude to my supervisor Professor Dr Wolfgang Lücke for his patient guidance, encouragement and excellent advice throughout this study. I am grateful to Professor Dr Pawelzik for continuous guidance, advice encouragement throughout the course of the thesis. Also, I thank Professor Dr Vidal for his approval to be a member of the examination board. My sincere thanks are to my advisor Dr Dieter von Höstren for his great support and frequent discussion.

Special thanks are made to the Staff at the Section of Agricultural engineering, Faculty of Agriculture, University of Göttingen for being very helpful in resolving official as well as technical issues. My sincere thanks are to Mr. Wegener, Martina, Rita, Marco, Ulrich, Anna Maria, Agus, Jakobs, Christian, Christoph, Maren, Adnan Sigg, Harry and Karsten for their technical assistance during the experimental work.

I also acknowledge my gratitude to my colleagues in the Department of Researches and Studies of Environmental Pollution, Environment and Natural Resources Research Institute (ENRRI), National Center for Research, Sudan for their continuous encouragement and support during the period of study.

I would like to express my gratitude to the German Academic Exchange Service (DAAD) for providing the financial support by providing the grant for me to peruse my PhD in Germany.

Last not the least, I would like to express my profound gratitude to my beloved parent, wife, and sisters for their moral support and patience during my study. I, therefore, dedicate this dissertation to them.

Table of contents

List of figures	v
List of tables	ix
Symbols and abbreviations.....	xi
1 Introduction	1
2 Literature review.....	5
2.1 Stored-products insects	5
2.2 Control methods of stored pest	6
2.2.1 Chemical control.....	6
2.2.2 Biological control.....	7
2.2.3 Physical control.....	7
2.3 Dielectric heating	12
2.3.1 Fundamental of dielectric heating.....	12
2.3.2 Dielectric heating mechanism.....	14
2.4 Dielectric properties of materials.....	15
2.5 Factors influencing the dielectric properties of materials.....	17
2.5.1 Moisture content	17
2.5.2 Temperature	19
2.5.3 Frequency	20
2.5.4 Bulk density	22
2.5.5 Other factors.....	22
2.6 Temperature distribution during dielectric heating.....	23
2.7 Principle of grains disinfestation using dielectric heating.....	24
2.8 Disinfestation of grains using dielectric heating.....	26
2.9 Influence of dielectric heating on grain quality	27

2.10	Conclusion.....	30
3	Materials and methods	31
3.1	Samples preparation	31
3.2	Insect culture	32
3.2.1	Adults rearing.....	32
3.2.2	Identifying of immature life stages	32
3.3	Microwave and radio frequency systems.....	32
3.3.1	Construction of the microwave system.....	32
3.3.2	Construction of the radio frequency system	35
3.4	Experimental design.....	36
3.5	Mortality of <i>Sitophilus zeamais</i>	38
3.5.1	Experimental design.....	38
3.5.2	Determination of mortality.....	39
3.5.3	Statistical analysis	40
3.6	Effect of microwave and radio frequency on maize grain quality.....	41
3.6.1	Determination of grains moisture content	41
3.6.2	Determination of Germination rate.....	41
3.7	Effect of microwave and radio frequency heating on the quality characteristics of maize flour	41
3.7.1	Experimental design.....	41
3.7.2	Preparation of the maize flour.....	42
3.7.3	Determination of dry matter of maize flour.....	42
3.7.4	Determination of Starch content in maize flour.....	43
3.7.5	Determination of crude protein content in maize flour.....	43
3.7.6	Determination of crude oil content in maize flour.....	44
3.7.7	Determination of fatty acid composition in maize flour.....	44
3.7.8	Determination of free amino acid in maize flour.....	44

3.7.9 Determination of free fatty acid in maize flour	45
3.8 Statistical analysis	45
4 Results.....	47
4.1 Heating rate of maize grains during microwave and radio frequency heat treatment	47
4.2 Mortality of <i>Sitophilus zeamais</i>	48
4.2.1 Mortality of <i>Sitophilus zeamais</i> life stages using microwave energy	48
4.2.2 Mortality of <i>Sitophilus zeamais</i> adults using radio frequency energy.....	56
4.3 Germination rates of maize grains	59
4.3.1 Effect of microwave heat treatments on the germination rate of maize grains	59
4.3.2 Effect of radio frequency heat treatments on the germination rate of maize grains	61
4.4 Effect of microwave heating on flour quality	63
4.4.1 Effect of microwave heating on the kernel composition of maize	63
4.4.2 Effect of microwave heating on the fatty acids composition of maize	65
4.4.3 Effect of microwave heating on the free amino acids contents of maize	70
4.4.4 Effect of microwave heating on the free fatty acids content of maize	74
4.5 Effect of radio frequency heat treatments on flour quality	76
4.5.1 Effect of radio frequency heat treatments on the kernel composition of maize	76
4.5.2 Effect of radio frequency heat treatments on the fatty acids composition of maize	78
4.5.3 Effect of radio frequency heat treatments on the free fatty acids content of maize	81

5 Discussion	83
5.1 Mortality of <i>Sitophilus zeamais</i>	84
5.1.1 Effect of temperature on the mortality of <i>S. zeamais</i> life stages during microwave and radio frequency treatments.....	84
5.1.2 Effect of initial grain moisture contents (IMCs) on the mortality of <i>S. zeamais</i> life stages during microwave and radio frequency treatments	86
5.1.3 Effect holding times on the mortality of <i>S. zeamais</i> life stages during microwave and radio frequency treatments.....	88
5.1.4 Susceptibility of <i>Sitophilus zeamais</i> life stages to microwave heating.....	89
5.1.5 Comparison of <i>S. zeamais</i> adult’s mortality in maize grains after microwave and radio frequency heat treatments	90
5.2 Effect of microwave and radio frequency heating on Germination of maize grains	94
5.3 Effect of microwave and radio frequency heat treatments on the maize flour quality	96
5.3.1 Effect of microwave and radio frequency heat treatments on the kernel composition of maize grains	96
5.3.2 Effect of microwave and radio frequency heat treatments on the fatty acids contents.....	97
5.3.3 Effect of microwave and radio frequency heat treatments on the free amino acids contents.....	98
5.3.4 Effect of microwave and radio frequency heat treatments on the free fatty acid content.....	99
6 Conclusion	101
7 Summary	103
8 Zusammenfassung	105
9 References	109

List of figures

Figure 2.1	Electromagnetic spectrum	13
Figure 2.2	Space charge and dipolar polarization in an alternating electric field at radio frequencies	15
Figure 2.3	Power flow when an electromagnetic wave strikes a dielectric material with high loss factor	16
Figure 2.4	Moisture dependence of the dielectric constant and loss factor of chickpea flour at various frequencies (MHz)	18
Figure 2.5	Dielectric properties of chickpea flour at 27 MHz as a function of temperatures and moisture contents.....	19
Figure 2.6	Dielectric properties of chickpea flour with 11.4% moisture content at different temperatures over the frequency range from 10 to 1800 MHz	21
Figure 2.7	Variation of the dielectric properties of bulk samples of adult rice weevils, <i>Sitophilus oryzae</i> , and of hard red winter wheat at 24°C from 50 kHz to 12 GHz.....	25
Figure 3.1	Schematic diagram of a laboratory microwave system	33
Figure 3.2	Microwave-control system screen display	34
Figure 3.3	Schematic diagram of the radio frequency unit.....	35
Figure 3.4	Radio frequency- control system screen display.....	36
Figure 3.5	Holding times at grain target temperature of 60°C	37
Figure 3.6	The schematic view of tray used in microwave treatments	37
Figure 3.7	The schematic view of tray used in radio frequency treatments....	38
Figure 4.1	Temperature rise of maize grains (14% IMC) subjected to microwave (300W) and radio frequency (300W) treatments.....	48

Figure 4.2	Mortality of <i>Sitophilus zeamais</i> adults after microwave heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).	49
Figure 4.3	Mortality of <i>Sitophilus zeamais</i> pupae after microwave heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).	50
Figure 4.4	Mortality of <i>Sitophilus zeamais</i> larvae after microwave heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).	51
Figure 4.5	Mortality of <i>Sitophilus zeamais</i> eggs after microwave heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min)..	52
Figure 4.6	Mortality of <i>Sitophilus zeamais</i> life stages after microwave heating at 45°C for 5 min in maize grains at different initial moisture contents (IMCs).	53
Figure 4.7	Mortality of <i>Sitophilus zeamais</i> adults after microwave heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).	54
Figure 4.8	Mortality of <i>Sitophilus zeamais</i> pupae after microwave heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).	55
Figure 4.9	Mortality of <i>Sitophilus zeamais</i> larvae after microwave heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).	55
Figure 4.10	Mortality of <i>Sitophilus zeamais</i> eggs after microwave heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).	56
Figure 4.11	Mortality of <i>Sitophilus zeamais</i> adults after radio frequency heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).	57

Figure 4.12 Mortality of <i>Sitophilus zeamais</i> adults after radio frequency heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).....	58
Figure 4.13 Germination rates of maize grains after microwave heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).....	60
Figure 4.14 Germination rates of maize grains after microwave heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).....	61
Figure 4.15 Germination rates of maize grains after radio frequency heating at different temperatures in maize grains at different initial moisture contents (IMCs) (holding time; 0 min).	62
Figure 4.16 Germination rates of maize grains after radio frequency heating at 50°C for different holding times in maize grains at different initial moisture contents (IMCs).....	63
Figure 4.17 Chromatogram of fatty acids in untreated maize sample	67
Figure 4.18 Chromatogram profile of 11 free amino acids in untreated maize sample.	71
Figure 5.1 Acceptable time-temperature treatment area obtained from different mortality and quality curves	83
Figure 5.2 Mortality of <i>Sitophilus zeamais</i> adults by using hot-air oven at different temperatures and holding times	86
Figure 5.3 Average of absorption power (a) and heating rate of the grains (b) during microwave treatments	87
Figure 5.4 Average of absorption power (a) and heating rate of the grains (b) during radio frequency treatments	88
Figure 5.5 Comparison of mortality rates of <i>Sitophilus zeamais</i> adult in maize of 14% IMC between microwave (2450 MHz) and radio frequency (27.13 MHz) treatment at different temperatures (holding time; 0 min)	91
Figure 5.6 Comparison of mortality rates of <i>Sitophilus zeamais</i> adult in maize of 14% IMC between microwave (2450 MHz)	

	and radio frequency (27.13 MHz) treatments at 50°C for different holding times	91
Figure 5.7	The dielectric loss factor of rice weevil, red flour beetle and sawtoothed grain beetle adults at 25°C.....	93
Figure 5.8	The dielectric loss factors of chestnut weevil adults at different frequencies and temperatures	94

List of tables

Table 2.1	Response of stored-products insects to temperature.....	10
Table 2.2	Federal Communications Commission allocated frequency bands designated for ISM applications	14
Table 3.1	Experimental design for the quality parameters	42
Table 4.1	The starch, crude protein and crude oil contents (DM) of maize grains at different initial moisture contents (IMCs) after microwave treatment at different temperatures (holding time; 1 min)	64
Table 4.2	The starch, crude protein and crude oil contents (DM) of maize grains after microwave treatment at 60°C for different holding times (IMC; 14%)	65
Table 4.3	Fatty acids contents (%) of maize grains at different initial moisture contents (IMCs) after microwave treatment at different temperatures (holding time; 1 min)	68
Table 4.4	Fatty acids contents (%) of maize grains after microwave treatment at 60°C for different holding times (IMC; 14%)	69
Table 4.5	Free amino acids contents (g/100g) of maize grains at different initial moisture contents (IMCs) after microwave treatment at different temperatures (holding time; 1 min).....	72
Table 4.6	Free amino acids contents (g/100g) of maize grains after microwave treatment at 60°C for different holding times (IMC; 14%).....	73
Table 4.7	Free fatty acids (FFA) contents of maize grains at different initial moisture contents (IMCs) after microwave treatment at different temperatures (holding time; 1 min)	74
Table 4.8	Free fatty acids (FFA) contents of maize grains after microwave treatment at 60°C for different holding times (IMC; 14%).....	75
Table 4.9	The starch, crude protein and crude oil contents (DM) of maize grains at different initial moisture contents (IMCs) after radio	

	frequency heat treatments at different temperatures (holding time; 1min)	76
Table 4.10	The starch, crude protein and crude oil contents (DM) of maize grains after radio frequency heat treatments at 60°C for different holding times (IMC; 14%).....	77
Table 4.11	Fatty acids contents (%) of maize grains at different initial moisture contents (IMCs) after radio frequency heat treatments at different temperatures (holding time; 1min)	79
Table 4.12	Fatty acids contents (%) of maize grains after radio frequency heat treatments at 60°C for different holding times (IMC; 14%)	80
Table 4.13	The Free Fatty acids content (DM) of maize grains at different initial moisture contents (IMC) after radio frequency heat treatments at different temperatures (holding time; 1min).....	81

Symbols and abbreviations

$\tan\delta$	Loss angle.	DNA	Deoxyribonucleic acid.
e	Euler`s number = 2.718.	FCC	Federal Communications Commission.
d_p	The electrical field penetration depth.	FO	Fiber optic.
^{137}C	Caesium-137	GC	Gas chromatography.
s			
^{60}Co	Cobalt-60	HPLC	High-performance liquid chromatography.
c	The speed of the light in free space (3×10^8 m/s).	ICC	International Association for Cereal Science and Technology.
f	Frequency (Hz).	IMC	Initial moisture content (%).
P	Power (W).	ISTA	International seed testing Association.
ΔT	The temperature rise ($^{\circ}\text{C}$).	kGy	Radiation absorbed dose measurement unit.
E	Electric field ($\text{V}\cdot\text{m}^{-1}$).	MW	Microwave.
Δt	Time increment (s).	RF	Radio frequency.
λ	Wavelength (m).	RH	Relative humidity.
C_p	The specific heat ($\text{Jkg}^{-1} \text{ }^{\circ}\text{C}^{-1}$).	rpm	Revolutions per minute.
ϵ'	Dielectric constant.	RVA	Rapid visco analyser.
ϵ''	Dielectric loss factor.	RVU	Rapid visco unit.
$\epsilon *$	The relative permittivity.	K	Kelvin , $\text{K} = [^{\circ}\text{C}] + 273.15$
ρ	The density (kgm^{-3}).		