INSTITUTE OF AGRICULTURAL ENGINEERING
University of Hohenheim
Tropics and Subtropics Group
Prof. Dr. J. Müller

Optimizing Small–Scale Longan (*Dimocarpus longan* Lour) Drying Industry in Northern Thailand

Dissertation
Submitted in fulfilment of the requirements for the degree
“Doktor der Agrarwissenschaften”
(Dr.sc.agr. / Ph.D. in Agricultural Sciences)

to the
Faculty of Agricultural Sciences
presented by

Marcus Nagle
from Dayton, Ohio

2010

This thesis was accepted as a doctoral dissertation in fulfilment of the requirements for the degree “Doktor der Agrarwissenschaften” by the Faculty of Agricultural Sciences at University of Hohenheim. on 26.01.2010

Date of oral examination: 01.06.2010

Examination Committee

Supervisor and Review	Prof. Dr. Joachim Müller
Co-Reviewer	Prof. Dr. Jens Wünsche
Additional examiners	Prof. Dr. Karlheinz Köller
Vice-Dean and Head of the Committee	Prof. Dr. Werner Bessei

This work was conducted within “Research for Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia” (SFB 564) funded by the Deutsche Forschungsgemeinschaft (DFG)

Schriftenreihe des Instituts für Agrartechnik in den Tropen und Subtropen der Universität Hohenheim
herausgegeben von Prof. Dr. Joachim Müller

Band 03/2010

Marcus Nagle

Optimizing Small–Scale Longan (*Dimocarpus longan* Lour) Drying Industry in Northern Thailand

D 100 (Diss. Universität Hohenheim)

Shaker Verlag
Aachen 2010

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.

Zugl.: Hohenheim, Univ., Diss., 2010

Printed in Germany.

ISBN 978-3-8322-9368-0
ISSN 1867-4631

Shaker Verlag GmbH • P.O. BOX 101818 • D-52018 Aachen
Phone: 0049/2407/9596-0 • Telefax: 0049/2407/9596-9
Internet: www.shaker.de • e-mail: info@shaker.de

Acknowledgement

To my supervisor, Prof. Dr. Joachim Müller for his indispensible advice, guidance and patience. To my Thai supervisors, Serm Janjai, Mahayothee Busarakorn, Methinee Haewsungcharern, Vicha Sardsud and Somchai Ongprasert for their sponsorship of the research activities in Thailand. To the Deutsche Forschungsgemeinschaft (DFG) and the Eiselen Foundation for their generous funding over the last years. To the staff at the Institute of Agricultural Engineering, many thanks for their daily assistance. To my ATS colleagues for their support and comradery.

To my colleagues in the Uplands Program, namely Wolfram, Noi, Stefi, Yok, Ae, Ben, Oy, Kanitta, Winai, Kanokwan, Noon, Mac and Anuwat for all their help in making this possible. To the staff, Lek and Peter. To my students, Juan Carlos, Franz, Kennedy, Marcelo, Barbara, Oy, Mae and Meow, I hope I was able to give them as much knowledge as they gave me. To Hermann and Sarawut, for teaching me more than you both realize. To my assistants, Num, Nid and Aing for your enthusiasm and dedication which was always appreciated.

To my family, Mom and Dad, Theresa, Vanessa, Erich, Irene, Chris and Anastasia for their unwavering love and support. To my grandparents, who believed I was capable of such an achievement long before I ever did. To Marco for standing by and helping with translations. To all my friends in Germany, Thailand, the United States and those who have scattered around the world, for giving me inspiration and motivation.

To the local people who gave their time to participate in my research, I hope this work will return you some benefit.

Thank you all.

Marcus

Contents

1 General introduction 1

1.1 Longan: botany, production and uses 1
1.2 Longan drying in Thailand 3
1.3 Renewable energy for longan drying 5
1.4 Objectives 7
1.5 References 7

2 Effects of operating practices on performance of a fixed–bed convection dryer and quality of dried longan 11

2.1 Introduction 11
2.2 Materials and methods 12

2.2.1 Characterization of drying conditions 14
2.2.2 Product quality analysis 15
2.2.3 Data analyses 16

2.3 Results and discussion 16

2.3.1 Characterization of drying conditions 16
2.3.2 Product quality analysis 22

2.4 Conclusions 25
2.5 References 26

3 Improved quality and energy performance of a fixed–bed longan dryer by thermodynamic modifications 29

3.1 Introduction 29
3.2 Materials and methods 31

3.2.1 Drying conditions 32
3.2.2 Product quality 34
3.2.3 Energy consumption 34

3.3 Results and discussion 35

3.3.1 Drying conditions 35
3.3.2 Product quality 38

3.3.3 Energy consumption 40

3.4 Conclusions 42
3.5 References 42

4 Potential of roof–integrated solar collectors for preheating air at drying facilities in northern Thailand 45

4.1 Introduction 45
4.2 Materials and methods 47

4.2.1 Survey of longan drying facilities 47
4.2.2 Measurement of required parameters 47
4.2.3 Evaluation of available collector materials 47
4.2.4 Gathering of radiation and weather data 48
4.2.5 Solar collector model 48
4.2.6 System simulation with TRNSYS 49
4.2.7 Additional calculations 50

4.3 Results and discussion 51

4.3.1 Overview of surveyed facilities 51
4.3.2 Available collector materials 51
4.3.3 Single–day performance of solar collectors 52
4.3.4 Seasonal performance of solar collectors 53
4.3.5 Variation of collector performance 56
4.3.6 Pressure drop through the roof collectors 57
4.3.7 Estimation of monetary savings 58

4.4 Conclusions 61
4.5 References 61

5 Fruit processing residues as an alternative fuel for drying in northern Thailand 63

5.1 Introduction 63
5.2 Materials and methods 65
5.3 Results 67
5.4 Discussion 73

5.4.1 Processing residues as fuel for direct combustion 74
5.4.2 Processing residues as feedstock for biogas production 75

5.5 Conclusions 75
5.6 References 76

6 Pruning wood as an alternative fuel for fruit drying in northern Thailand . 81

6.1 Introduction 81
6.2 Materials and methods 84

6.2.1 Quantification of pruning practices 84
6.2.2 Drying of pruning wood 84
6.2.3 Fuel analysis of pruning wood 85

6.3 Results 87

6.3.1 Quantification of pruning practices 87
6.3.2 Drying of pruning wood 90
6.3.3 Fuel analysis of pruning wood 91
6.3.4 Economic analysis of pruning wood as fuel 93

6.4 Discussion 93

6.4.1 Quantification of pruning practices 93
6.4.2 Drying of pruning wood 94
6.4.3 Fuel analysis of pruning wood 95

6.5 Conclusions 96
6.6 References 97

7 General discussion 101

7.1 Potential of dryer design modifications 101
7.2 Potential of renewable energy for fruit drying 102
7.3 Conclusions 104
7.4 Outlook 105
7.5 References 107

8 Summary 109
9 Zusammenfassung 113

List of figures

Fig 1–1. Examples of longan fruit. 1
Fig 1–2. Taiwan–type longan dryer. 4
Fig 1–3. Local biomass residues and drying facility with a solar roof collector. 6
Fig 2–1. Diagram of a Taiwan–type dryer 13
Fig 2–2. Positioning of measurement points and arrangement of drying layers. 13
Fig 2–3. Shifting schemes of treatments. 14
Fig 2–4. Positioning of the fruit samples 15
Fig 2–5. Air velocity distribution in the dryer while empty and full 17
Fig 2–6. Temperature distribution at various bulk heights during drying 18
Fig 2–7. Drying conditions during the first drying shift 20
Fig 2–8. Changes in sample moisture content from treatments by drying layer. 21
Fig 2–9. Distribution of moisture content of samples for each treatment. 23
Fig 2–10. Relation between moisture content and hue angle. 24
Fig 3–1. Self–innovation at local drying facilities 31
Fig 3–2. Modification of the dryer plenum 32
Fig 3–3. Shifting procedures of bulk layers 32
Fig 3–4. Positions of sensors in the drying bulk layers. 33
Fig 3–5. Measurement positions of plenum temperature and air velocity 33
Fig 3–6. Horizontal distribution of air velocity in dryers per modification 36
Fig 3–7. Horizontal distribution of air temperature in the plenum during drying 37
Fig 3–8. Thermal images of the dryer unmodified and modified dryer. 37
Fig 3–9. Mean temperature of the bulk layers by drying shift. 38
Fig 3–10. Drying curves by bulk position 39
Fig 3–11. Pigment content of samples by layer 40
Fig 4–1. Examples of longan drying facilities in Thailand 46
Fig 4–2. Outlet temperatures of a solar collector on an average day 53
Fig 4–3. Seasonal solar fraction for facilities with air channels of 10 cm. 54
Fig 4–4. Seasonal solar fraction for facilities with air channels of 5 cm. 55
Fig 4–5. Seasonal efficiency for drying facilities 55
Fig 4–6. Pressure drop through solar collectors for drying facilities. 59
Fig 4–7. Economic savings and cost of materials for drying facilities. 60
Fig 5–1. Fruit composition in terms of peel and seed residues 69
Fig 5–2. Bulk density of peel, seed and endocarp residues 69

Fig 5–3. Measured higher heating values of fruit processing wastes versus values estimated by literature models 71
Fig 6–1. Examples of litchi pruning in Mae Rim district.. 83
Fig 6–2. Pruning wood production as related to orchard age.................................. 88
Fig 6–3. Distribution of pruning wood diameters per age category......................... 89
Fig 6–4. Drying curves of mango wood 90
Fig 6–5. Drying rates of mango, litchi and longan wood 91

List of tables

Table 2–1. Mean values for final moisture content and hue angle by layer 20
Table 2–2. Mean values for final moisture content and hue angle by treatment..... 25
Table 3–1. Average temperature and relative humidity in the bulk and final moisture content of longan 39
Table 3–2. Dryer performance by modification 41
Table 3–3. Economic evaluation of dryer modification 41
Table 4–1. Characteristics of longan drying facilities 51
Table 4–2. Properties and price of transparent cover materials.............................. 52
Table 4–3. Properties and price of glasswool insulation 52
Table 4–4. Collector output depending on roof pitch and collector size................. 56
Table 4–5. Collector output depending on azimuth angle and collector size.......... 57
Table 5–1. Analyzed fuel parameters for fruit processing residues 67
Table 5–2. Literature models used to estimate higher heating value of fruit procesing residues 67
Table 5–3. Results of the fruit processing facility survey 68
Table 5–4. Results from proximate analysis of peel and seed wastes 70
Table 5–5. Model accuracy for estimating higher heating value of fruit procesing residues 71
Table 5–6. Ultimate analysis of fruit processing wastes 72
Table 6–1. Analyzed fuel parameters for pruning wood residues 86
Table 6–2. Literature models used to estimate higher heating value of pruning wood residues 86
Table 6–3. Descriptive data from results of the pruning survey.............................. 87
Table 6–4. Pruning wood production for two age categories.................................. 88
Table 6–5. Results from fuel analysis of pruning wood samples 92
Table 6–6. Model accuracy for estimating higher heating value of pruning wood residues 92
Table 6–7. Economic analysis of pruning wood as fuel.. 93

Nomenclature

AAE	Average absolute error
AC	Ash content (% wt db)
FC	Fixed carbon (% wt db)
HHV	Higher heating value (MJ kg^{-1})
LPG	Liquefied petroleum gas
MC	Moisture content, wet basis (% wb)
RH	Relative humidity (%)
RMSE	Root mean square error
SEE	Specific evaporation energy (MJ kg^{-1})
SF	Solar fraction
SPE	Specific production energy (MJ kg^{-1})
T	Temperature (ºC)
THB	Thai baht
VM	Volatile matter (% wt db)
HHV_{exp}	Experimental higher heating value (MJ kg^{-1})
HHV_{pre}	Predicted higher heating value (MJ kg^{-1})
E_t	Total energy supplied to the dryer in form of electric and heat (MJ)
h^o	Hue angle (º)
m_e	Mass of water evaporated from the bulk (kg)
m_p	Mass of dried product (kg)
MC_f	Final moisture content (% wb)
MC_i	Inital moisture content (% wb)
η	Thermal efficiency (%)
$RH_{P(x)}$	Relative humidity at position (x) (%)
T_a	Ambient temperature (ºC)
$T_{P(x)}$	Temperature at position (x) (ºC)
T_τ	Dew point temperature (ºC)