UNIVERSITI PUTRA MALAYSIA

DESIGN AND DEVELOPMENT OF A SEEDING MACHINE FOR SYSTEM OF RICE INTENSIFICATION SEEDLING TRAY

TUKUR DAIYABU ABDULKADIR

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By

TUKUR DAIYABU ABDULKADIR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for Degree of Doctor of Philosophy

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DEDICATION

This thesis is dedicated to my late father Daiyabu Abdulkadir Minjibir and my beloved mother Habiba Daiyabu.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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Chairman : Muhammad Razif Mahadi, PhD
Faculty : Engineering

The manual seeding of the system of rice intensification (SRI) seedling tray is labor and time intensive, therefore, there is need to have a machine for the seeding process. In this study a seeding machine for SRI seedling tray was designed, developed and evaluated. The use of vacuum suction as a tool for single seeding of paddy seed to SRI seedling tray was conceived. The amount of vacuum pressure required for single seeding of MR219 paddy seed was determined using existing models and evaluated experimentally. Cone angle and seed-hole diameter as important nozzle parameters were determined and evaluated experimentally. A vacuum seeding manifold with 924 seeding nozzles was proposed for the SRI seedling tray seeding process. Computational fluid dynamic (CFD) software was used to optimize the manifold design, where the effect of number of suction outlets on vacuum pressure uniformity was investigated. The effect of vacuum chamber type on vacuum pressure distribution uniformity was also investigated, where two manifold types with cylindrical and rectangular vacuum chambers were compared using CFD. Two types of pick and place mechanisms, which are screw mechanism and crank rocker mechanism, were proposed and compared analytically for best performance in terms of operational speed. The strength of the links of the crank-rocker pick and place mechanism was simulated using finite element analysis (FEA). The flow property of seedling growing media in relation to hopper material surface was studied using Jenike's procedure, where the optimum hopper angle was determined for development of seedling media hopper. A seeding machine was developed for SRI seedling tray. The machine consists of three basic sub systems synchronized to work as a single unit, these are: media placement system that place planting media to the seedling cavities before and after seed placement; seed placement system that place single seed per seedling cavity; and tray conveying systems that transport the seedling tray from beginning to the end of the seeding process. In operation, one operator places a seedling tray on the conveyor at one end of the seeding machine. The conveyor transports it to pass below a media hopper. A first layer of media is sprayed on the tray. When the tray reaches seed placement section, an object detection sensor detects its presence and stops the

conveyor. The seed placement mechanism picks the seeds from a seed tray and places them into the seedling cavities with the aid of vacuum suction and solenoid valve. The tray is then transported to pass below a second media hopper where the seeds are covered. A third operator removes the seeded tray from the conveyor. The machine performance was evaluated based on media placement and single seeding capability. The amount of vacuum for single seeding of MR219 seeds was found to be between 18.3 and 29.15 mbar. Experimental evaluation of this vacuum pressure has shown that the optimum vacuum pressure for single seeding of paddy seed is 30 mbar. The optimum seed-hole diameter was found to be 1 mm and was adopted for the seeding manifold development. The effect of number of suction outlets on vacuum pressure distribution uniformity was not significant. For seeding manifold with 924 seeding nozzles, manifold with rectangular vacuum chamber type was found to have a better pressure distribution uniformity than manifold with cylindrical vacuum chamber type. Crank-rocker mechanism with a theoretical operational period of 1 second per pick and place circle was found to have a better performance than the screw mechanism with 78.8 second per pick and place circle. A safety of factor of 4.64 ul was obtained from the FEA analysis for mechanism links. The hopper angle for mass flow of planting media was found to be 22^{o}. The evaluation results of the seed placement mechanism have shown that seeding without seed tray vibration has a better performance, where the best performance of 75% single seeding, 0% multiple seeding and 25% miss seeding was achieved. The results of evaluation with vibrating seed tray have shown a top performance of 46% single seeding, 0% multiple seeding and 54% missed seeding. A mean media depth of 18.32 mm was achieved. The field capacity and efficiency of the machine were found to be 1 tray/14 s (1 ha/ 0.67 hour) and 61.43% respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor falsafah

REKABENTUK DAN PEMBANGUNAN MESIN PERCAMBAHAN UNTUK DULANG PERCAMBAHAN SISTEM PENINGKATAN BERAS

Oleh

TUKUR DAIYABU ABDULKADIR

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Kajian ini menumpukan kepada rekabentuk dan pembangunan mesin untuk pembenihan padi berdasarkan *SRI Tray* yang telah dipatenkan. Penggunaan sistem tekanan vakum sebagai alat untuk meletakkan benih padi tunggal ke dulang benih SRI telah dibina. Jumlah tekanan vakum yang diperlukan untuk pembenihan tunggal biji padi MR219 ditentukan melalui pembangunan model sedia ada dan dinilai melalui eksperimen. Sudut kon denganaliranberlubang adalah parameter reka bentuk muncung yang penting, telah ditentukan dan dinilai secara eksperimen. Manifestasi pembenahan vakum dengan 924 muncung pembenihan telah dicadangkan untuk proses pembenihan dulang benih SRI. Perisian *Computational Fluid Dynamic*(CFD) digunakan untuk mengkaji kesan saiz pancarongga pembenihan terhadap keseragaman pengedaran tekanan vakum dan kesan bilangan cabangpenyedut pada pancarongga. Kesan jenis kebuk vakum pada keseragaman pengedaran tekanan vakum telah dianalisa, yang mana dua jenis pancaronnga dengan jenis kebuk vakum silinder dan segi empat tepat dibandingkan. Dua jenis mekanisme pemilihan dan penempatan, yang merupakan mekanisme skru dan mekanisme aci-gerak, telah dicadangkan dan dibandingkan analitik untuk prestasi terbaik dari segi kelajuan operasi. Kekuatan hubungan mekanisme angkat dan aci-gerak disimulasi menggunakan kaedah *Finite Element Anlysis* (FEA). Sifat aliran media tumbuhan yang berkaitan dengan permukaan bahan corong dikaji menggunakan prosedur Jenike, yang man sudut corong ditentukan untuk perkembangan corong media anak benih. Mesin pembenihan dulang benih telah dibangunkan untuk pembenihan *SRI Tray*. Prestasi mesin dinilai berdasarkan pada penempatan media dan keupayaan penempatan benih tunggal. Nilai tekanan vakum untuk pembenihan tunggal biji padi MR219 didapati antara 18.3 hingga 29.15 mbar. Penilaianujikaji tekanan vakum ini untuk penempatan benih padi tunggal telah menunjukkan bahawa 30 mbar adalah tekanan vakum operasi yang terbaik untuk penempatan benih padi tunggal. Diameter lubang 1 mm didapati mempunyai prestasi yang lebih baik dan telah digunakan untuk pengembangan panca rongga. Didapati, keseragaman pengedaran tekanan vakum boleh dijejaskan oleh saiz pancarongga.

Kesan bilangan sedutan pada keseragaman pengedaran tekanan vakum didapati tidak berperanan penting. Bagipancarongga dengan 924 pembekas, panca rongga dengan jenis ruang vakum segi empat tepat didapati mempunyai keseragaman pengagihan tekanan yang lebih baik daripada pancarongga jenis kebuk vakum silinder. Mekanisma aci-gerak dengan tempoh operasi teori 1 saat per angkut dan lingkaran tempat ditemukan memiliki prestasi yang lebih baik daripada mekanisma skru dengan tempoh operasi 78.8 saat per angkut dan tempat lingkaran. Faktor Keselamatan 4.64 diperolehi daripada analisis FEA untuk hubungan mekanisme. Sudut corong untuk aliran massa media penanaman didapati 22. Mesin pembenihan telah dibangunkan. Hasil penilaian mekanisma penempatan benih menunjukkan bahawa pembenihan tanpa getaran biji benih mempunyai prestasi yang lebih baik, di mana prestasi terbaik 75% pembibitan tunggal, 0% berbiji dan 25% diperolehi. Hasil penilaian dengan dulang benih bergetar telah menunjukkan prestasi tertinggi sebanyak 46% pembibitan tunggal, 0% berbiji dan 54% tanaman tidak tersasar.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Rice is a major staple in most countries in Asia (Mallikarjuna, et al., 2015) and also an important food crop in Africa (Terdoo and Feola, 2016). Demand for rice is increasing proportionally to the increase of population. The production of rice covers all regions of the world, and about 90% of global rice is produced in Asia (Muthayya, et al., 2014). Rice cultivation has been mechanized in most Asian countries and other developed nations, but the cultivation is predominantly manual in most African producing countries.

The System of Rice Intensification (SRI) was introduced in 1983 in Madagascar by Henri de Laulanie. It has been reported that SRI could generate higher yield with minimal water usage than conventional rice cultivation method. Other important benefits of SRI include reduction in greenhouse gases emission and use of chemicals. In SRI, the management of rice, water and soil was re-defined to exploit the genetic potentials of the variety. Single young rice seedlings are planted in a well prepared soil with a constant spacing of usually 25 × 25 cm between and within the rows. Water application is intermittent, unlike the constant flooding in conventional rice cultivation practice. Over the years, SRI has spread to different parts of the world including Malaysia. However, this cultivation technique requires intensive labor. The future adoptability of SRI depends on reduction in the labor involved, which could be achieved through mechanization of the cultivation process. The mechanization of single seedling transplant could be achieved with seedlings that are raised singly.

At Universiti Putra Malaysia (UPM) a unique SRI seedling tray was developed and patented by Bashar, et al., (2015). The tray was aimed at mechanizing SRI cultivation method. It has 924 rectangular seedling cavities, each with a depth of 30 mm, in which each cavity is targeted at raising single seeds. Upon development, the tray was successful in raising single vigor seedlings. The next development stage should be the mechanical system for seeds preparation based on the tray.

1.2 Problem Statement

Crop establishment in rice cultivation is a labor intensive operation accounting for about 42% of the total labor in rice production (Sangeetha and Baskar, 2015). The labor requirement in the seedling establishment of the system of rice intensification SRI is more than that of the conventional rice cultivation practice. This additional labor is witnessed in field marking, and transplant of single seedling per crop stand. The high labor demand is the major setback faced by researchers and promoters of SRI in convincing the farmers to adopt it, despite the higher yield attribution. Efforts are being made by researchers and a number of farmers to mechanize the seedling establishment process of SRI. Little success was reported in this respect. Until now, there is no commercial SRI transplanter available to farmers. From a deeper understanding of labor in SRI, mechanization is the main option to its adoptability.

In Bashar et al., (2015) a single seedling tray based on SRI was developed. The tray was able to raise single seedling with unconnected roots. In addition, it was estimated that 173 units were required to raise sufficient seedlings for a hectare of land.

However, the operational characteristics such as the labor versus time required for completion of work was not mentioned. Therefore, in this study, a brief experiment was conducted, in order to estimate the values. Firstly, the time required to fill a single SRI seedling tray with planting media and single seed per seedling cavity manually was 34 minutes. Hence, the field capacity of the manual seeding process was 98.03 h/ha or 1630 cells/h. The labor in the manual seedling of the tray is considered high when compared to 38,800 cells/h achieved mechanically by Gaikwad and Sirohi (2008). Hence, the need arise for mechanizing the seeding process of the SRI seedling tray with the aim of reducing the labor intensity of the tray seeding process, which could eventually motivate farmers to the adoption of SRI cultivation. The adoption or modification of the existing seedling tray seeding machines requires each subsystem of the machine to be modified, as each seedling tray seeding machine is unique in design, targeting specific tray and seed types. Hence, development of a new machine is considered a better approach.

The abovementioned problem indicates that the constraint can be addressed through innovation in the placement of seeds manipulation. Several existing techniques were reviewed and discussed in detail in Chapter 2. It was found that, due to the shape of the paddy seed, manipulation based on vacuum pressure may have a better potential than other methods. Initial study presented by Rosli et al., (2016) in defining a workable conveyor design was also used as the basis of this research.

1.3 Objectives of the study

The main objective of this study is to develop an automated seeding machine for the seeding of SRI seedling tray.

To achieve the main objective the following specific objectives are considered:

1. To study the critical parameters in the pneumatic handling of paddy seeds using vacuum suction.
2. To design a seed placement mechanism that utilizes vacuum pressure manipulation based on the patented SRI seedling tray.
3. To develop a conveyor based paddy seeding machine for the patented SRI seedling tray.

4. To estimate the expected field capacity of the seeding machine and its operational cost.

1.4 Scope and Limitations

This study covers conceptual development, engineering design, computational fluid dynamic (CFD) simulation and finite element analysis (FEA) simulation of the critical components of a seeding machine for the system of rice intensification (SRI) seedling tray. The seed design parameters considered in this study are those of MR219 seed. The choice of MR219 was based on its higher yield and being the common rice variety cultivated in Peninsular Malaysia. The machine was designed to be used for seeding MR219 paddy seed to the patented SRI seedling tray. Consideration was not made to other seeds or other varieties of rice. No consideration was made to other seedling trays. The planting media considered in this study comprised of loamy soil and organic compost in the ratio 1:1. The planting media is to be mixed manually prior to loading it into the hopper. The seed is to be cleaned prior to loading it to the seed tray on the machine. The machine was designed for indoor usage. The machine was designed with an expected field capacity of 0.5h/ha.

1.5 Thesis Outline

The thesis is organized into six chapters. Chapter one consist of overview of global rice production, consumption, relationship between world population growth and increase in rice production, an overview of SRI and SRI seedling tray. Literature related to global rice production, Malaysian rice production, the system of rice intensification, machines in pick and place applications and automated conveyor system were discussed in chapter two. The methods used in study of critical parameters in the pneumatic handling of paddy seed, the design process of seedling tray seeding machine and the development of the seedling tray seeding machine were reported in Chapter three. The result of the entire study is reported in Chapter four. The overall research summary, conclusions reached at the end of the study and recommendation for future work were reported in chapter five. The references of the literature cited in the thesis were reported in the list of references. Appendices mentioned in the thesis were reported in the list of appendices.

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LIST OF PUBLICATIONS

Journal article:

Tukur Daiyabu Abdulkadir, Muhammad Razif Mahadi, Aimrun Wayayok, Muhamad Saufi Mohd Kassim (2019): Critical Parameters on Pneumatic Handling of Paddy Seed by Vacuum Pressure. Agricultural Engineering International (Scopus). Published

Tukur Daiyabu Abdulkadir, Muhammad Razif Mahadi, Aimrun Wayayok, Muhamad Saufi Mohd Kassim (2018): Optimization of Vacuum Based Manifold Design for Seeding of SRI Seedling Tray. Accepted by Cogent Engineering (Scopus)

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