Operational parameters affecting pneumatic paddy seeds

Tukur Daiyabu Abdulkadir[1*], Muhammad Razif Mahadi[1,2], Aimrun Wayayok[1,2], Muhamad Saufi Mohd Kassim[1,2]

(1. *Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia;*
2. *SMART Farming Technology Research Center, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia*)

Abstract: This study was carried out to determine the critical operational parameters for pneumatic handling of MR219 paddy seeds, with emphasis to seeding of system of rice intensification (SRI) seedling tray. The relevant physical and aerodynamic properties of MR219 seeds were studied. Twenty nozzle designs were developed based on the physical properties. A suitable operational vacuum pressure for single paddy seed picking was determined from established models based on one thousand kernel mass M_{1000}, true density, sphericity and projected area of MR219 paddy seed. The performances of the twenty nozzle designs were evaluated experimentally using an automated platform consisting of screw mechanism, vacuum manifold, solenoid valve, vacuum pump and Atmel microcontroller. The amount of vacuum suction required for single seed picking derived from the established models was found to be 18.30 to 29.15 mbar. However, the amount of vacuum suction was optimized experimentally where 25 to 30 mbar was found to be suitable vacuum pressure for single seeding of MR219 paddy seed using 1 mm to 1.5 mm seed-hole diameter. The highest performance of 96.7% single seeding, 3.3% multiple seeding, and 0% miss seeding was achieved using nozzle with 1 mm seed hole diameter at 30 mbar vacuum pressure.
Keywords: single seed placement, SRI Tray, aerodynamic properties, pneumatic handling, suction, paddy seed

Citation: Abdulkadir, T. D., M. R. Mahadi, A. Wayayok, and M. S. M. Kassim. 2019. Operational parameters affecting pneumatic paddy seeds handling using vacuum pressure. Agricultural Engineering International: CIGR Journal, 21(2): 59–69.

1 Introduction

One of the major challenges in the System of Rice Intensification (SRI) practice is high labor demand in crop establishment. Planting of single, healthy and young rice seedling per crop stand is a basic requirement in SRI. The process remains predominantly manual. Mechanizing this process will make a vital contribution towards farmer SRI adoption. The conventional way of raising rice seedling produces dense seedling population with interwoven root system. This combined with the seedling picking mechanism design makes single seedling planting a difficult or rather an impossible process. The raising of uniformly spaced single seedlings on a seedling tray at the seedling nursery is a basic step in achieving SRI mechanization. Single seedling trays (Plug trays) have been used for decades to raise single seedlings at the seedling nursery by vegetable farmers. The conventional process of seeding specialized SRI trays is manual. The mechanized seeding process of plug trays has limitation to the type of tray and crop it could be used for. The manual seeding of specialized SRI tray developed by Bashar et al. (2014) is time and labor intensive. A number of single seedling tray seeding machines for vegetables and orchard plants have been developed by a number of researchers and manufacturers, but that of rice seed remains a gap to be filled. Nursing of rice seedling on single seedling tray is not a practice in conventional rice cultivation. The conventional mechanical rice seedling tray seeding processes do not prioritize spacing between seeds. Since SRI has such a requirement, the use of

Received date: 2018-03-15 **Accepted date:** 2018-05-25
*** Corresponding author: Tukur Daiyabu Abdulkadir,** Ph.D., Candidate Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia. Email: dantukuro@gmail.com. Tel: +60143264652, +2348081096618, Fax: 603-8946 6425.

pneumatic seeding could be an effective way of addressing the major challenges in SRI seedling nursery.

In the design of any agricultural and non-agricultural machines, study of some critical operational parameters is a basic and vital stage. These critical parameters could lead to an optimum design process. The critical parameters could be the properties of the material to be handled, the operational speed of the machine or any of their kind.

Mechanical seeding of seedling tray is a research area that has been explored by researchers and manufacturers. Vacuum (pneumatic) seeding is one of the effective ways of achieving single seeding. An optimum design of pneumatic seeding and handlings machines depends on comprehensive understanding of the relevant physical and aerodynamic properties of the target seed. In the pneumatic handling of agricultural seeds, two approaches are usually used. The first involves the use of terminal velocity of the seed, and the second involves quantifying the vacuum suction required using physical properties.

Studies on seed and grain physical properties were carried out by a number of researchers for different purposes. Henrita et al. (2015) studied physical properties of Adan rice seed for the purpose of seed quality evaluation. The parameters measured were moisture content, length, width, thickness, 1000 grain mass, sphericity, geometric mean diameter, surface area aspect ratio and true density.

Many researchers have developed single seedling tray seeding machines of different designs, targeted at different crops. Gaikwad and Sirohi (2008) developed a single seedling tray seeder for tomatoes and capsicum seeds to enhance seedling production rate and supplement labor shortage faced by seedling producers of India. The machine consists of an array of 24 nozzles mounted on aluminum cylindrical hollow pipe, spaced equally with desired spacing. The pipe is mounted on a frame supported by bushings, a vibrating seed tray is mounted beside the nozzle bearing pipe. A plug tray filled with media is placed on a belt conveyor just below the suspended nozzles. Seeds are picked from the seed tray as the shaft bearing nozzles rotates towards the seed tray. Picking and dropping of seed is controlled by a suction pump and solenoid valve. The nozzles feed a single row of the tray at a time. The seeder achieved a seeding rate of 38,800 cells h^{-1}. This machine was tested with more than 90% success in single seeding for both subjects. The design is specific and could not be applied to other seeds with significant varying properties. Sriwongras and Dostal (2013) developed a manually operated mechanical plug tray seeder for round seeds. The machine performed well at 7.88 times faster than the manual seeding, with seed placement efficiency of 79% using papaya seed. Gezavat et al. (2015) developed a plug tray seeder for tomatoes, to address the high labor demand in manual seeding and increase nursery productivity. In an attempt to adopt a seedling tray seeding machine for maize bowl-tray nursery in cold regions, Xin et al. (2015) conducted experiments to optimize operational parameters and evaluate the seeder performance, where they achieved single seeding rate of 94.29%. Naik and Thakur (2017) developed an automated plug tray seeder for vegetable seeds.

The nursing of rice seedling on single seedling trays is not a common practice in conventional rice cultivation. No literature accessible to us reported such a practice because conventional rice cultivation does not require single seedlings. The success of SRI crop establishment mechanization relies on the successful development of singly spaced seedlings. In an attempt to mechanize SRI crop establishment, Dhananchezhiyan et al. (2013) developed a new seedling raising technique that raises seedlings which are widely and uniformly spaced, through the use of corrugated aluminum mat placed on the conventional rice seedling tray. Holes with the shape of paddy seeds were made on the mat. The mat is then laid unto the media in the tray. Single seeds were then placed to each hole manually. The mat is then taken off the tray, leaving singly spaced paddy seeds on the media. The technique is a milestone in SRI mechanization process, though it has associated problems of high labor demand and possibility of the roots getting interwoven which may affect the transplanting process and subject seedlings to unwanted shock during seedling transplant.

Development of a precision seed placement method for specialized SRI tray using vacuum technology has the potential of addressing a number of questions in SRI mechanization process. Vacuum seeding system could produce seedlings that are suitable for SRI crop establishment mechanization. The vacuum seeding system should be able to utilize vacuum suction generated by a vacuum pump, to pick a single paddy seed per seed nozzle from a seed tray, and precisely place it to a seedling cavity on SRI seedling tray. The success of this concept depends on the comprehensive understanding of the theoretical and empirical aerodynamic characteristics of the paddy seeds. The objective of this paper is to study the critical parameters for handling of paddy seeds by means of vacuum pressure. The results from this study should serve as the fundamental in the design of MR219 seed handling device based on vacuum pressure.

2 Materials and methods

2.1 Theoretical background of vacuum manipulation

2.1.1 Nozzle-seed kinematics

The process of object manipulation using vacuum suction involves the interaction of the object, suction pressure, gravitational effect, mechanical disturbances and picking device. Consider using a vacuum suction nozzle to pick a paddy seed from a seed container (Figure 1). The suction force F_{vac} provided by a vacuum pump should be sufficient to overcome the gravitational force F_g acting on the seed due to gravitational attraction of the earth and adhesion force F_a between the seed and the seed container. Equation (1) is used to describe this relationship. When the seed is at the tip of the nozzle and is at placement position, the gravitational force F_g must be greater than the suction force plus the adhesion force between the seed and the nozzle tip for the seed to drop off the nozzle as described by Equation (2). At this position the vacuum suction is closed, making F_{vac} zero and Equation (3) is used to describe the condition for seed to drop off the nozzle.

$$F_{vac} > F_a + F_g \tag{1}$$

where, F_{vac} is vacuum suction force, N; F_a is adhesion force between seed and seed tray, N; F_g is gravitational force, N.

$$F_a > F_{vac} + F_a \tag{2}$$

$$Fa > Fa \tag{3}$$

In a state of static equilibrium, a metered seed will remain in contact with the tip of a pneumatic nozzle when the gravitational attraction on the seed F_g is balanced by the static pressure F_D acting on the projected area of the seed A_p (Figure 2). In the static situation the pressure difference in Pascal (Pa), between one point below and one point above the seed that is being held in static position denoted by P_o is given in Equation (4).

Assuming $F_D = F_g$ at static equilibrium

$$P_o = F_D/A_p = M_p g/A_p \tag{4}$$

where, P_o is pressure difference, Pa; F_D is the drag force due to vacuum suction, N; A_p is the projected area of the seed, m^2; M_p is the mass of the particle (single seed), kg; g is the gravitational acceleration, m s^{-2}; D_o is the seed hole diameter, mm.

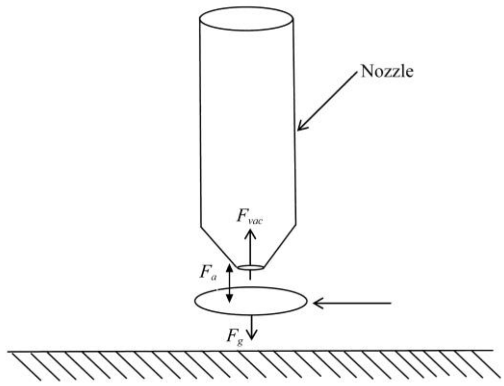


Figure 1 Seed- nozzle interaction

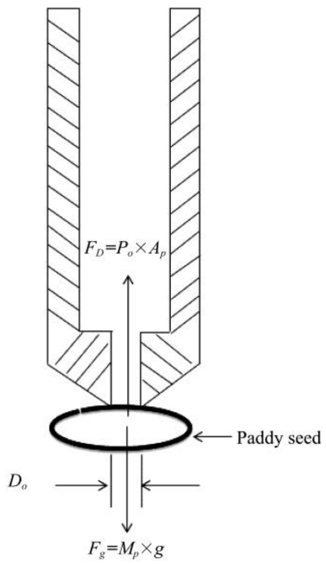


Figure 2 Seed- nozzle kinematics

In dynamic state, for the seed to remain at the nozzle tip, the air velocity V_a must be greater than the terminal velocity of the seed V_t, due to the effect of vibration. The pressure difference P_d, holding the seed on the tip of the nozzle is described by Fallack and Persson (1984) (Equations (5)-(6)). The terminal velocity of the seed is the air velocity at which it just become suspended in a vertical stream of air

$$P_d = 0.5\rho_a v^2 t \tag{5}$$

$$M_p g = 0.5C_d\rho_a A_p v^2 t \tag{6}$$

From Equations (4), (5), and (6)

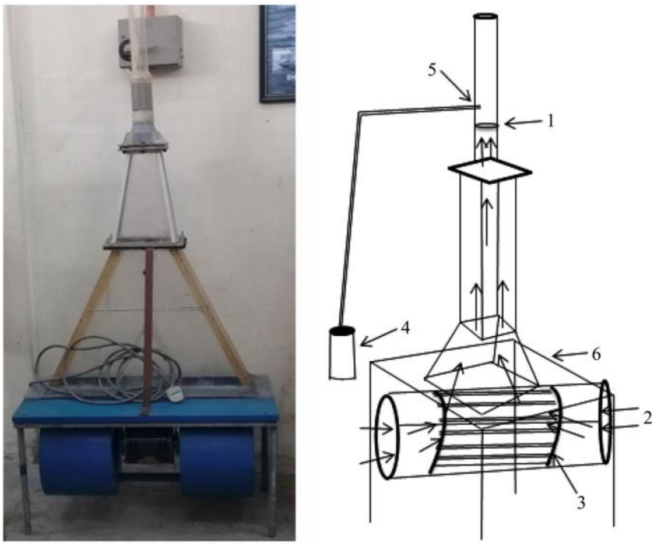
$$P_o = F_D/A_p = 0.5C_d\rho_a A_p v^2 t/Ap = 0.5C_d\rho_a v^2 t = C_d P_d$$

$$P_o = C_d P_d \tag{7}$$

where, P_d is dynamic pressure difference, Pa; C_d is drag coefficient, dimensionless; ρ_a is the density of air, kg m^{-3}; F_D is the drag force, N; v_t is the terminal velocity of the seed, m s^{-1}; P_o is pressure difference, Pa.

2.2 Aerodynamic properties

The use of vacuum suction to pick a seed from the seed tray, retain it at the tip of a pneumatic nozzle during transport to the placement position, made the study of the aerodynamic properties of paddy seed a vital component of this study. The terminal velocity of an object placed in a vertical air channel, is that air velocity at which the object is just suspended in the air channel. At this velocity the gravitational attraction on the object is balanced by the upward pull of the air stream. Terminal velocity is an important parameter in the design of pneumatic seeding machine, pneumatic conveyor, seed dryer and pneumatic seed cleaning machines. Terminal velocity of MR219 rice seed was studied using a vertical air flow chamber shown in Figure 3. Figure 3(a) present a picture of the device, while Figure 3(b) presents a schematic diagram of the device showing the various components. A single MR219 seed was placed on the wire mesh (1), an air flow (2) was generated by a blower (3), the air velocity was gradually increased using the blower speed regulator, a digital anemometer (4) connected to the flow channel just above the wire mesh (5), was used to monitor the air velocity. All the components were supported by a frame (6). The air velocity at which the seed just began to float in the channel was recorded as the terminal velocity of the seed. This experiment was replicated three times for dry seed, primed seed and pregerminated seed. The moisture content of each of the seed treatments was measured prior to the terminal velocity measurement using G-7 grain moisture meter manufactured by Delmhorst Instrument Co.



(a) Picture of the device (b) Schematics of the device

Figure 3 Terminal velocity measurement device

2.3 Physical properties of paddy seed: Geometric mean diameter, sphericity, 1000 kernel mass, and true density

The study of relevant physical properties of the popular rice variety (MR219) cultivated in Selangor State, Malaysia was conducted. The paddy seed was obtained from Tanjung Karang, one of the major rice cultivation areas of Selangor State, Malaysia. After cleaning the seed of dust and other foreign materials, a sample of 100 quality seeds was randomly selected for study of relevant physical properties. The seed dimensions: length L, width W, and thickness T as the basic parameters of physical properties were measured using Hexagon Metrology Optiv Lite 2515 Figure 4 with an accuracy of 0.0001 mm for higher precision, minimal mechanical deformation and user convenience.

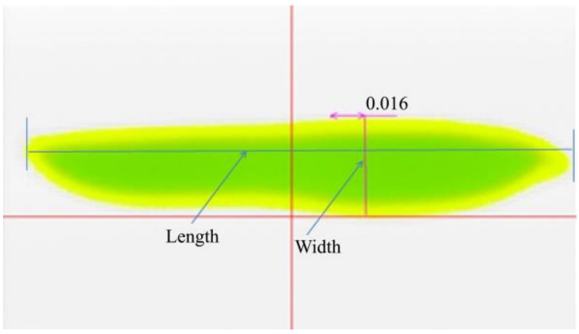


Figure 4 Paddy dimensions measurement

Geometric mean diameter, sphericity and percentage of sphericity: Paddy geometric mean diameter D_g was calculated from the measured dimensions using Equation (8). The sphericity of MR219 was calculated as a ratio of D_g to L using Equation (9).

The percentage sphericity is calculated by multiplying sphericity by 100. Sphericity was defined as the ratio of surface area of an object to the surface area of a sphere of the same volume as the object in question (Wadell, 1935; Zheng and Hryciw, 2015). Li et al. (2012) reported that sphericity is an important shape parameter for non-spherical objects, it is one of the most important factors used in determining porosity for engineering applications. Sphericity ranges between 1 for perfect sphere to 0 for objects with non-spherical feature.

$$D_g = (LWT)^{2/3} \tag{8}$$

where, L, W, and T are length, width and thickness of the paddy seed respectively, mm; D_g, is geometric mean diameter, mm

$$Ø = D_g/L \tag{9}$$

where, Ø is sphericity of the seed, unitless.

Conventionally, the geometric mean diameter D_g is used to determine the seed hole diameter of a vacuum seeder nozzle using ≤ 0% D_g as recommended by Singh et al., (2005) in the design of conventional vacuum seed planter for spherical seeds. Using the same condition above on paddy seed may result in higher multiple seeding rate, with the possibility of blockage of the nozzle due to seed being swollen using the upper limit of ≤ 50% geometric mean diameter. The square root of the product of width and thickness $(WT)^{1/2}$ is another parameter introduced to determine the optimum seed hole diameter for non-spherical seeds such as paddy.

1000 kernel mass: To determine one thousand kernel mass M_{1000} of MR219 seed, clean 1000 seeds sample was randomly selected and weighed using a digital weighing balance TX423L with an accuracy of 0.0001 g. The measurement was replicated three times and the mean value calculated.

True density and projected area: True density was calculated by placing 1000 seeds sample in a measuring cylinder, the volume occupied was recorded as bulk volume of 1000 seed. Water was used to fill the pore spaces between seeds, without exceeding the initial bulk volume level in the cylinder. The water was drained, collected and its volume measured and recorded as pore space volume. The true volume is the bulk volume less volume of the pore space. The true density was computed as a ratio of M_{1000} to true volume Vol_t using Equation (10). Projected area of MR219 paddy seed was measured using Hexagon Metrology Optiv Lite 2515. The projected area of a seed is the area occupied by the seed natural resting position

$$D_t = M_{1000}/vol_t \tag{10}$$

where, D_t is true density of MR219, kg m^{-3}; M_{1000} is mass of single seed, kg; Vol_t is true volume of the seed, m^3.

Seed nozzle: Twenty nozzle designs were developed based on nozzle seed-hole diameter and cone angle shown in the schematic diagram in Figure 5. The square root of the product of width and thickness was used in determining the seed-hole diameter. Four different nozzle diameters: 0.5 mm, 1 mm, 1.5 mm, and 2 mm were used each on five different cone angles: 0°, 30°, 60° 90°, 120°. The twenty nozzles were fabricated using stainless steel rod of 10 mm diameter and 60 mm length each. Four mm diameter hole was drilled from the nozzle base to a depth of 50 mm. The remaining 10 mm length which is the conical part of the nozzle was drilled with the 0.5 mm, 1 mm, 1.5 mm and 2 mm diameter, each for the five cone angles.

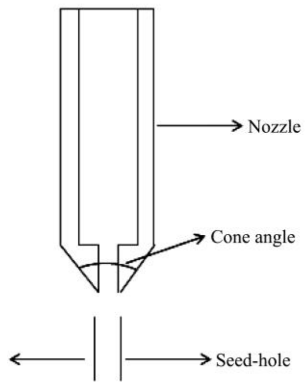


Figure 5 Cross section of seeding nozzle

2.4 Operational vacuum pressure

To obtain the optimum vacuum pressure required to pick a single paddy seed using vacuum nozzle, hold it at the nozzle tip and transport it to the seeding position, mathematical models developed by Karayel et al. (2004) based on physical properties of seeds were adopted in this study. These physical properties are 1000 kernel mass M_{1000}, true density, sphericity and projected area of the seed.

2.4.1 Based on 1000 kernel mass

$$P = 1.18(M_{1000})0.2 \tag{11}$$

where, M_{1000} is 1000 kernel mass, kg; P is the vacuum pressure needed to pick a single seed, kPa; R^2 is coefficient of determination.

2.4.2 Based on true density

$$P = 0.002(\rho_t) + 1.02 \tag{12}$$

where, ρ_t is true density of the seed, kg m^{-3}; R^2 is coefficient of determination.

2.4.3 Based on sphericity

$$P = 0.04(Ø) + 0.43 \tag{13}$$

where, Ø is sphericity of the seed,%; R^2 is coefficient of determination.

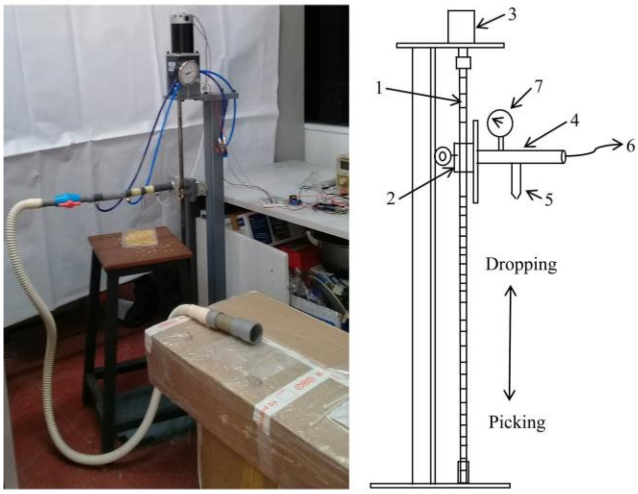
2.4.4 Based on projected area

$$P = 1.96(A_p)^{0.11} \tag{14}$$

where, A_p is projected area the seed, mm^2; R^2 is coefficient of determination.

2.5 Performance evaluation of single seed picking capability of vacuum nozzle

The performance of a vacuum seeder depend on several variables that interacts in complex way (Guarella et al., 1996). These parameters are dimensions of the nozzle, shape, size and weight of the seed. The single seed picking capability of each of the 20 nozzles design was tested using an automated platform shown in Figure 6(a). Figure 6(b) is the schematic diagram of the platform showing its various components. The platform is basically a vertical leadscrew mechanism to which other vital components are coupled. This consists of a vertical screw (1) that moves the manifold up and down for picking and placement, a carriage (2) that connect the manifold to the screw mechanism, a DC motor (3) that drives the screw, cylindrical vacuum manifold (4) mounted to the carriage to which a nozzle (5) was attached. The manifold is connected to a solenoid valve at the other end (6) through a pneumatic hose. The solenoid valve was connected to a vacuum pump. The vacuum pump provides the necessary suction in the range of 15 mbar to 30 mbar used in the evaluation process for seed picking. A manually operated valve was placed between the solenoid valve and the vacuum pump, to regulate and preset a fix amount of suction into the manifold via the solenoid valve prior to automatic picking commencement. A vacuum gauge (7) is connected to the manifold for vacuum setting and monitoring. A microcontroller was used to automate the downward and upward motion of the manifold during which the seed is picked and dropped respectively. The solenoid valve was controlled using the same microcontroller, to open for suction during seed picking, and close during seed placement.



(a) Picture (b) Schematics

Figure 6 Nozzle performance test set up

This evaluation process involves a total of 80 treatments derived from five cone angles: 0º, 30º, 60º, 90º and 120º, four nozzle-hole diameter: 0.5, 1, 1.5, and 2 mm, and four different vacuum pressure levels: 15, 20, 25, and 30 mbar. That is each of the 20 nozzle designs was tested at four levels of pressure. In this evaluation process, each of the 80 nozzle treatments was used to pick 10 seeds in three replicates. The nozzle cone angle, nozzle diameter and vacuum pressure as independent variables, where number of seeds picked was dependent variable. The mean value of the performance indices: single seed count, multiple seed count and miss seed count were observed and recorded.

2.5.1 Percentage of single seed pick-up

This parameter is used to define the percentage of picking attempts that resulted in single paddy seed being picked at the nozzle tip of one particular nozzle. This is referred to as the success rate. The success rate is a combine effect of the nozzle-hole diameter and operational vacuum pressure. A good design of vacuum single seeding machine is one that resulted in the highest possible single seeding rate, with minimum multiple and miss seeding.

2.5.2 Percentage of multiple seed pick-up

This parameter is used to define the percentage of picking attempts that resulted in multiple seeds being picked at the tip of a particular nozzle. High multiple seeding is a result of bigger nozzle seed-hole diameter, higher operational vacuum pressure, or a combine effect of both. A good vacuum single seeding machine should have minimum possible multiple seeding. Though having multiple seeding is better than having missed seeding.

2.5.3 Percentage of missed seed

This parameter is used to define the percentage of picking attempts that resulted in zero seed at the tip of a particular nozzle. This happened as a result of low vacuum pressure at the nozzle tip, small nozzle seed-hole diameter, or a combine effect of low pressure and smaller seed-hole diameter. Miss seeding should be minimized to the lowest possible level and even eliminated if possible. Machine with high miss seeding will result in the need for re seeding which result in additional cost of production or less yield where reseeding is not carried out.

3 Results and discussion

3.1 Physical and aerodynamic properties

Based on MR219 paddy seed specimens, the relevant physical properties were studied and recorded (Table 1). The mean seed length was found to be 10.20 mm with a standard deviation of 0.49 mm. The mean seed width was found to be 2.37 mm with a standard deviation of 0.16 mm. The mean thickness of the seed was found to be 1.87 mm with a standard deviation of 0.09 mm.

Table 1 Physical properties of MR219 paddy seed

Physical property	Minimum	Maximum	Mean	Stand. Deviation
Length (mm)	8.72	11.48	10.20	0.49
Width (mm)	2.04	2.74	2.37	0.16
Thickness (mm)	1.57	2.02	1.87	0.09
Geometric mean diameter (mm)	3.28	3.79	3.56	0.11
$WT^{1/2}$ (mm)	1.9	2.33	2.1	0.08
Sphericity (unit less)	0.31	0.39	0.35	0.02
Percentage of sphericity (%)	31	39	35	-
True density (kg m^{-3})	-	-	947	-
1000 kernel mass (g)	-	-	25.6	-
Projected area (mm^2)	13.4	16.3	15.3	0.27

The values of geometric mean diameter were calculated from the principal dimensions; length, width and thickness. The value was found to be 3.56 mm, eventually, the values of geometric mean diameter were used to optimize the seed-hole diameter of the vacuum nozzle through comparison of sphericity characteristic.

It was determined that the sphericity of MR219 seed was 0.35 and conformed to the findings of Usman et al., (2015). In comparison to 0.41 sphericity of ADT-43 rice variety (Ravi and Venkatachalam, 2014), 0.37 sphericity of IR-36 rice variety reported by (Reddy and Chakraverty, 2004) MR219 has a lower sphericity, though other rice variety (Heshami) was reported to have similar sphericity (0.345) with MR219 (Alizadeh et al., 2006). In comparison to the sphericity values (Φ = 0.71-0.75) for corn by Babic et al. (2013), (Φ = 0.87-0.97) for Bambera groundnut by Zenabou et al. (2016) and (Φ = 0.689) for cotton seed by Karayel et al. (2004), MR219 seeds showed lower spherical characteristics, hence, it could be regarded as a non-spherical seed.

The conventional method of determining seed-hole diameter recommended ≤50% geometric mean diameter without a boundary. The use of <20% geometric mean diameter of MR219 seed, within the range of vacuum pressure calculated previously will result in higher miss seeding, otherwise a higher vacuum pressure needs to be used.

The failure of the conventional method of optimizing seed-hole diameter on paddy seed, due to the non-spherical nature of MR219 made the seed length an insignificant parameter in computing seed-hole diameter in comparison to the thickness and width, due to the wide gap between the length, and width and thickness. This compelled us to develop another parameter: the square root of the product of width and thickness of the seed $(WT)^{1/2}$. The nozzle diameter recommended for this design is 45%-70% the square root of the product of width and thickness $(WT)^{1/2}$ of the seed. Nozzle of this hole diameter would be able to pick single seed, with minimum incidence of multiple and miss seeds. The use of this range of hole diameter have resulted in the seed hole being fully closed by the seed.

Results of the aerodynamic properties study of MR219 seed is presented in Table 2. Three treatments: dry seed, primed seed and pregerminated seed were used in this study. Results of the moisture content measurement of the three treatments is also reported in Table 2. The moisture content of these treatments varies, with primed seed having highest moisture content, followed by pre germinated seed and dry seed has the least. A difference in terminal velocity was observed among the three treatments used. Primed seed has the highest moisture content of 29.1% (wb), dry untreated seed has the least moisture content of 12.26% (wb). Terminal velocity was found to increase with an increase in moisture content of the seed. This is as a result of increased mass. Similar relation was observed by Tabak and Wolf (1998) on cotton seed; Shahbazi et al. (2014) on Makhobeli, Triticale and Wheat seed and Shahbazi (2015) on Mung Bean seed.

Table 2 Effect of moisture content on aerodynamic properties of MR219 seeds

Treatment	Moisture content (%) wb	Mean Terminal velocity ($m\ s^{-1}$)
Dry Seed	12.26	5.77
Primed Seed	29.1	6.45
Pre-germinated Seed	28.23	6.27

3.2 Operational vacuum pressure

The operational vacuum pressure obtained using the adopted four models described in the materials and method is reported in Table 3. The vacuum pressure value ranges between 18.30 mbar obtained based on sphericity to 29.15 mbar obtained based on true density. The range between the four models is 10.85 mbar. The variation in vacuum pressure among the different models used will account for the dynamic nature of agricultural seeds, which eventually will result in higher single seeding rate, with minimum missed and multiple seeding. The vacuum range of 10.85 mbar is only about half the least vacuum pressure computed from the adopted models, while minimizing double seeding, the highest vacuum suction of 29.15 mbar will be sufficient to pick the biggest possible MR219 seed. The highest vacuum of 29.15 mbar obtained in this study is less than 40 mbar obtained for maize, 30 mbar obtained for cotton, soya beans and water melon seeds, which have higher weight than paddy seed, and is higher than 20 mbar and 15 mbar obtained for sugar beet and onions seeds respectively (Karayel et al., 2004), which have lower weight than paddy seeds.

Table 3 Operational vacuum pressure

Model	Vacuum pressure (mbar)
Based on M_{1000}	22.57
Based on true density	29.15
Based on sphericity	18.30
Based on projected area	26.46

3.3 Developed nozzle designs

The twenty nozzles designs developed from a combination four cone angles and five seed-hole diameters are shown in Figure 7.

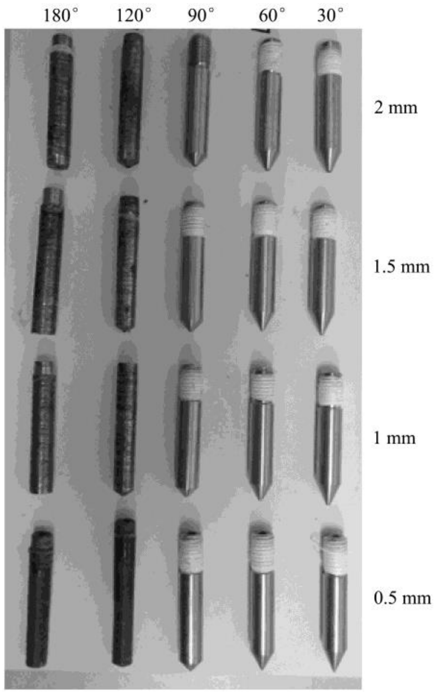


Figure 7 Single seed Nozzles

3.4 Effect of nozzle design on system performance

A summary of the performance indices of the 20 nozzle designs is shown in Table 4. Overall 80 treatments were used for this evaluation process, meaning each nozzle was tested at four different pressure levels. From each of the 20 nozzle designs, a treatment with the highest rate of success is reported in Table 4. Not much variation was observed in success rate among the different cone angles. In other word the effect of adhesion force between nozzle tip and seed was not significant on the single seeding performance of seeding nozzle, though it can still play a role in minimizing mechanical damage during seed picking, as seed picking is centered to a single seed due to the minimum nozzle tip dimension.

The seed-hole diameter of the nozzles has a great impact on the nozzle performance, with the best performance in terms of highest single seeding rate observed on nozzle with 1 mm seed-hole diameter for 0^o, 60^o and 120^o nozzles. 1.5 mm seed-hole diameter was found to have highest performance for nozzles with 30^o and 60^o cone angles. The highest multiple seeding was observed on nozzles with 2 mm diameter for all the five nozzle angles. The highest missed seeding was observed on nozzle with 0.5 mm diameter for all the nozzle angles. This means the higher the seed-hole diameter is, the higher the multiple seeding. The lower the seed-hole diameter is, the higher is the miss seeding. An optimum seed-hole diameter must therefore be used for the best possible performance of the seeding system.

Table 4 Effect of cone angle, nozzle diameter and vacuum pressure on single seed picking

S/N	Cone angle (degree)	Diameter (mm)	Pressure (mbar)	% Single seed (%)	% Multiple seed (%)	% Missed seed (%)
1	120	1	30	96.7	3.3	0
2	0	1	30	93.3	6.7	0
3	30	1.5	25	93.3	3.3	3.3
4	60	1.5	15	86.7	13.3	0
5	60	1	30	80	0	20
6	90	1.5	15	76.7	20	3.3
7	0	1.5	20	73.3	26.7	0
8	90	1	30	73.3	0	26.7
9	120	1.5	15	66.7	23.3	10
10	60	2	15	53.3	46.7	0
11	90	2	30	53.3	46.7	0
12	0	2	15	36.7	63.3	0
13	30	1	30	36.7	0	63.3
14	120	2	20	23.3	76.7	0
15	30	2	20	10	90	0
16	90	0.5	20	6.7	0	93.3
17	0	0.5	30	3.3	0	96.7
18	60	0.5	20	3.3	0	96.7
19	30	0.5	15,20,25,30	0	0	100
20	120	0.5	15,20,25,30	0	0	100

The amount of vacuum pressure was found to be a vital parameter that affects nozzle performance. Among the 20 nozzle designs, 30 mbar operational vacuum pressure performed best for nozzles with 0º and 120º cone angle. 25 mbar vacuum pressure performed best for nozzles with 30º cone angle. 15 mbar vacuum pressure performed best for nozzle with 60º cone angle. In general the performance of the nozzle in terms of single seeding capability is a combine effect of operational vacuum pressure and seed-hole diameter, but is not affected by nozzle cone angle. Though, the nozzle cone angle is an important parameter in minimizing mechanical damage to the seed.

In general, nozzles with 1 mm seed-hole diameter have the best performance of highest single seeding, minimum multiple seeding and lowest miss seeding at 30 mbar vacuum pressure. Nozzles with 0.5 mm seed-hole diameter have the lowest performance with the lowest single seeding of zero values in most situations, zero multiple seeding and highest missed seeding with 100% values in most cases, at all the vacuum pressure levels considered.

Another important parameter affecting the nozzle performance is the natural seed orientation on the seed tray. This parameter is difficult to be quantified or influenced. The seed natural orientation can influence single seeding when the seed was able to fully close the seed-hole, multiple seeding when the seed-hole is only partially closed, thereby giving a chance for a neighboring seed to be picked, as well and missed seeding where empty space was created by random seed arrangement. Some level of seed tray shaking can enhance the single seeding capability of a nozzle based seeder.

The best 20 performances from the overall 80 treatments are reported in Table 5. The overall best performance of 96.7% single seeding, 3.3% multiple seeding and 0% missed seeding was achieved with 1 mm seed-hole diameter nozzle at 30 mbar vacuum pressure. For all the best 20 performances out of the 80 treatments, only 1mm and 1.5 mm seed-hole diameter were present in the list. This implies that 1 mm to 1.5 mm seed-hole diameter is the optimum for nozzle based vacuum seeding of MR219 seed. The 0.5 mm seed-hole diameter results in high missed seeding with some values reading as low as 100%. The 2 mm seed-hole diameter results in low single seeding rate with some treatments resulting to as low as 0%, while others have a few multiple seeding.

Table 5 Performance of twenty best of the overall eighty treatments

S/No	Cone angle (degree)	Hole diameter (mm)	Pressure (mbar)	%Single seed (%)	%Multiple seed (%)	%Missed seeds (%)
1	120	1	30	96.7	3.3	0
2	30	1.5	25	93.3	3.3	3.3
3	0	1	30	93.3	6.7	0
4	120	1	20	90	0	10
5	60	1.5	15	86.7	13.3	0
6	30	1.5	30	83.3	16.7	0
7	0	1	20	83.3	10	6.7
8	0	1	25	83.3	10	6.7
9	60	1	30	80	0	20
10	30	1.5	20	76.7	16.7	6.6
11	90	1.5	15	76.7	20	3.3
12	0	1	15	76.7	6.7	16.6
13	30	1.5	15	73.3	0	26.7
14	120	1	25	73.3	0	26.7
15	90	1	30	73.3	0	26.7
16	0	1.5	20	73.3	26.7	0
17	60	1.5	25	70	30	0
18	60	1.5	30	70	26.7	3.3
19	0	1.5	15	70	30	0
20	120	1.5	15	66.7	23.3	10

4 Conclusion

The critical parameters for the pneumatic handling of MR219 paddy seed were determined. The mean terminal velocity of dry, primed and pregerminated MR219 paddy seed were 5.77 m s^{-1}, 6.45 m s^{-1} and 6.27 m s^{-1} respectively. There exists a relationship between seed moisture content and terminal velocity. The higher the moisture content of paddy seed the higher is its terminal velocity.

The use of the established models based on M_{1000}, true density, sphericity and projected area for predicting the vacuum suction for single seeding of MR219 paddy seed was effective way of determining suitable vacuum pressure for single seed picking usifng vacuum suction. The amount of vacuum pressure derived were 22.57 mbar using M_{1000}, 29.15 mbar using true density, 18.30 mbar using sphericity and 26.46 mbar using projected area of the seed. At the evaluation level, the best performance of 90%-96.7% was achieved at a pressure of 20-30 mbar. The higher vacuum suction was a result of additional vibrations in the testing platform. The best performing vacuum suction was within the vacuum pressure computed from the adopted models.

The single seeding performance of the nozzle is affected by nozzle seed-hole diameter. The best nozzle seed-hole diameter for pneumatic single seeding of MR219 paddy seed is 1 mm. Nozzles with bigger seed-hole diameter results in multiple seeding, smaller seed-hole diameter results in high miss seeding rate.

The single seeding performance of the nozzle was not affected by the nozzle cone angles within the range of 0^{o} to 120^{o} nozzle angle tested, but use of pointed tip of 30^{o} is recommended, to reduce the total weight of the device, reduce mechanical damage to the nearby seeds during seed picking and avoid high rate of missed seeding due to poor seed natural orientation.

Acknowledgements

This work was funded by Universiti Putra Malaysia Grant scheme (PUTRA-IPB). Grant number 9442501.

References

Alizadeh, M. R., S. Minaei, T. Tavakoli, and M. H. Khoshtaghaza. 2006. Effect of de-awning on physical properties of paddy. *Pakistan Journal of Biological Sciences*, 9(9): 1726–1731.

Babic, L. J., M. Radojcin, I. Pavkov, M. Babic, J. Turan, M. Zoranovic, and S. Stanisic. 2013. Physical properties and compression loading behaviour of corn seed. *International Agrophysics Journal*, 27(2): 119–126.

Bashar, Z. U., A. Wayayok, and A. M. S. Mohd. 2014. Determination of some physical properties of common Malaysian rice MR219 seeds. *Australian Journal of Crop Science*, 8(3): 332–337.

Dhananchezhiyan, P., C. D. Durairaj, and S. Parveen. 2013. Development of nursery raising technique for system of rice intensification machine transplanting. *African Journal of Agricultural Research*, 8(29): 3873–3882.

Fallack, S. S., and S. P. E. Persson. 1984. Vacuum nozzle design for seed metering. *Transaction of the ASAE*, 27(1): 688–696.

Gaikwad, B. B. Ã., and N. P. S. Sirohi. 2008. Design of a low-cost pneumatic seeder for nursery plug trays. *Biosystems Engineering*, 99(3): 322–329.

Gezavati, J., D. M. Zamani, M. Abbasgolipour, B. A. Mohammadi, and A. Randhi. 2015. Preliminary design, construction and evaluation of robot of tomato seed planting for the trays of greenhouse. *Journal of Agricultural Machinery*, 5(2): 242–250.

Guarella, P., A. Pellerano, and S. Pascuzzi. 1996. Experimental-and-theoretical-performance-of-a-vacuum-seeder-nozzle-for-vegetable-seeds. *Journal of Agricultural Engineering Resources*, 64(1): 29–36.

Henrita, S., J. Make, N. A. P. Abdullah, B. Petrus, W. Y. Wan Asrina, O. H Ahmed, and A. R. Muhammad. 2015. Seed quality, physical properties and proximate composition of adan rice. In *Proceeding Kuala Lumpur International Agriculture, Forestry and Plantation*, 54-58. Hotel Putra, Kuala Lumpur, Malaysia, 12-13 September.

Karayel, D., Z. B. Barut, and A. Özmerzi. 2004. Mathematical modelling of vacuum pressure on a precision seeder. *Biosystems Engineering*, 87(4): 437–444.

Li, T., S. Li, J. Zhao, P. Lu, and L. Meng. 2012. Sphericities of non-spherical objects. *Particuology*, 10(1): 97–104.

Naik, D. A., and Thakur, H. M. 2017. Design and analysis of an automated seeder for small scale sowing applications for tray plantation method. *International Journal of Engineering Research and Technology*, 10(1): 716–723.

Ravi, P., and T. Venkatachalam. 2014. Important engineering properties of paddy. *Agricultural Engineering*, 39(4): 73–83.

Reddy, B. S., and A. Chakraverty. 2004. Physical properties of raw and parboiled paddy. *Biosystems Engineering*, 88(4): 461–466.

Shahbazi, F., S. Valizadeh, and A. Dowlatshah. 2014. Aerodynamic properties of makhobeli, triticale and wheat seeds. *International Agrophysics*, 28(3): 389–394.

Shahbazi, F. 2015. Evaluation and modeling of aerodynamic properties of mung bean seeds. *International Agrophysics*, 29(1): 121–126.

Singh, R. C., G. Singh, and D. C. Saraswat. 2005. Optimization of design and operational parameters of a pneumatic seed metering device for planting cottonseeds. *Biosystems Engineering*, 92(4): 429–438.

Sriwongras, P., and P. Dostal. 2013. Development of seeder for plug tray. *MendelNet*, 24(1): 867–871.

Tabak, S., and D. Wolf. 1998. Aerodynamic properties of cottonseeds. *Journal of Agricultural and Engineering Research*, 70(3): 257–265.

Usman, Z. B., A. Wayayok, M. S. M. Amin, and M. R. Mahadi. 2015. Single seedling nursery tray : an innovative breakthrough to quality seedling raising technique for SRI transplanting machine. *Research Journal of Applied Sciences, Engineering and Technology*, 10(11): 1258–1265.

Wadell, H. 1935. Volume, shape and roundness of quartz particles. *The Journal of Geology*, 43(3): 250–280.

Xin, M., Y. juan, T. Xiang, Y. Li, L. Yan, and M. Cai. 2015. Experimental study on seed-filling performance of maize bowl-tray precision seeder. *International Journal of Agricultural and Biological Engineering*, 8(2): 31–39.

Zenabou, N., B. J. Martin, O. Bassiaka, M. S. Ebenye, N. H. Bille, and F. Daniel. 2016. Variation in seeds physical traits of Bambara groundnut (Vigna Subterranea) collected in Cameroon. *American Journal of Experimental Agriculture*, 12(2): 1–8.

Zheng, J., and R. D. Hryciw. 2015. Traditional soil particle sphericity, roundness and surface roughness by computational geometry. *Géotechnique*, 65(6): 494–506.

Nomenclature

Notation	Description	Notation	Description
MR219	Rice variety	C_d	Drag coefficient, dimensionless
SRI	System of rice intensification	L	Length, mm
F_{vac}	Vacuum Suction force, N	W	Width, mm
$\underline{F_a}$	Adhesion force, N	T	Thickness, mm
F_g	Gravitational force, N	D_g	Geometric mean diameter, mm
F_D	Drag force, N	Ø	Sphericity, dimensionless
P_S	Static pressure, kPa	M_{1000}	1000 kernel mass, kg
P_o	Static Pressure difference, kPa	$WT^{1/2}$	Root of the product of mass and width, mm
M_p	Mass of single particle, kg	D_t	True density, kg m^{-3}
A_p	Projected area, mm^2	Vol_t	True volume, m^3
G	Gravitational attraction, m s^{-2}	M	Bulk mass, kg
P_t	Dynamic pressure difference, kPa	P	Vacuum pressure, kPa
ρ_a	Density of air, kg m^{-3}	R^2	Coefficient of determination
v_t	Terminal velocity, m s^{-1}	wb	Wet basis