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RESEARCH ARTICLE

Impact of moisture content on seed quality of combine-harvested rice varieties

R Jeya Chandra[1], P Masilamani[1*], B Suthakar[2], P Rajkumar[1], S D Sivakumar[3] & V Manonmani[4]

[1]Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur 621 712, Tiruchirappalli, Tamil Nadu, India
[2]Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[3]Institute of Agriculture, Tamil Nadu Agricultural University, Kumulur 621 712, Tiruchirappalli, Tamil Nadu, India
[4]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - masilamanip@tnau.ac.in

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Abstract

The study was conducted with different rice varieties *viz.,* TRY 3, CO (R) 50 and ADT 54 harvested using a tractor driven combine harvester with John Deere two wheel drive tractor across distinct moisture contents at various stages *viz.,* at physiological maturity, two days, four days and six days after physiological maturity stage. The treatments aimed to deduct seed quality evaluation through physical parameters *viz.,* broken seed, dehusked seed, pure seed and husk percentage, seed to husk ratio, mechanical properties and physiological properties of seed was evaluated using ferric chloride and further, whereas physiological parameters such as germination, seedling growth and vigour index. The result showed that harvesting at physiological maturity achieved 91 % germination rate, which subsequently decreased at six days after maturity stages to 86 %. Whereas seeding length, dry matter production and seedling vigour obtained during physiological maturity stage and six days after maturity stage of root length 24.6 cm and 22.7 cm, shoot length as 13.1 cm and 10.4 cm, dry matter as 0.150 and 0.121 (g/10 seedling), vigour index of 3350 and 2843 respectively. The chemical method using ferric chloride, detected 7.7 to 8.4 % mechanical damage irrespective of the varieties studied with different moisture levels. However, germination percentage from harvesting at physiological maturity stage or four to six days after maturity stages which maintain more than 80 % germination irrespective of the varieties studied and satisfied the Indian Minimum Seed Certification Standards.

Keywords: combine harvester; mechanical damage; moisture content; rice; seed quality

Introduction

Rice is a staple crop produced on a large scale in India, which occupies a production of 135.75 million tonnes, cultivated across an area of 47.83 million hectares, with a productivity of 2838 kg ha^{-1} (1). In rice production, harvesting is an essential process, often associated with a substantial yield loss (2). Maintaining seed quality throughout harvest and post-harvest handling is important for sustaining seed viability, germination and vigour, which have a direct impact on crop yield and quality. Post harvest losses occur due to various factors like climatic conditions and environmental factors that lead to crop delay. Premature or early harvest results in immature seeds, shrivelled seeds, bird and pest attacks and an overall reduction in crop yield. The late harvesting cause shattering of seeds, seed breakage and quality loss (3).

Manual harvesting and threshing with sickles, typically performed by human labour, is a time consuming and labour-intensive process. It is also costly and often causes delays, leading to seed loss, seed quality deterioration, seed shattering and mechanical damage (4, 5). Threshing, cleaning and winnowing also cause various problems with post-harvest losses, seed breakage, without removal of proper stones, debris, chaffy materials in the rice seed (5, 6). To overcome these techniques of traditional rice harvesting such as high labour costs, time inefficiencies and potential crop losses, harvesting and threshing can be done by using mechanized harvesting of combine harvester offers an effective solution leads low-cost production and improved labour efficiency. Combine harvester is more efficient than traditional harvesting method, which combines all the operations into single action like reaping, threshing and winnowing of crop seed (7). Physiological maturity stage is the correct stage for harvesting the rice crop at 80 % of the grains turned to straw yellow colour with moisture content of 20-25 % (7). Using this method, enables farmers to not only saves time, but also saves labour and costs, with the reduction of 10 % post-harvest losses with high germination 97 % (8), while ultimately improves the output and profit quality parameters and storage behaviour effects on seed harvesting, losses and viability over time (6).

However, the improper adjustment in combine harvester can lead to mechanical damage with reduced seed quality. These factors impact not only seed yield but also storage, inadequate drying, seed spillage, seeds damaged during harvesting or threshing contributes to viability loss during storage, which results reduction in a germination potential. To prevent the mechanical losses, we harvest the crop at the ideal moisture content at 20-25 %. Therefore, the need for more efficient and timely agricultural operations is paramount to ensure optimal crop yield and mitigate the negative impacts on post-harvest and seed quality. Improvements in cultivation technology, which continue to evolve over time, have proven to be highly effective in significantly enhancing rice production. Seed quality is the most important factor influencing crop growth, development and yield processes and could increase yield by 5-20 %. Harvesting, threshing and cleaning plays a significant role in realizing the full benefit of raised crop by reducing post-harvest losses as well as improving quality of rice. These operations play a vital role for protecting seed viabilitiy/germination. Improper harvesting, threshing and cleaning may cause loss of seed germination/viability. Before recommending the best adoptable harvesting and threshing method we need to understand their effect on seed quality *viz.,* germination (%) and seedling vigour etc. By addressing these issues, the study describes harvesting the rice crop using combine harvester with the moisture content and effects on seed quality and yield.

Materials and methods

An experiment was carried out in 2024 at the Department of Applied Sciences and Engineering at Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur and Sugarcane Research Station (SRS), Sirugamani. To evaluate the effect of harvesting rice seed crop using combine harvester on seed quality parameters across different moisture content and physiological maturity stages on rice varieties *viz.,* TRY 3, CO (R) 50 and ADT 54. The harvest was carried out by KS 513 TD - tractor driven combine harvester with John Deere two wheel drive tractor. It is a 55 hp wheel type harvester, machine suitable for paddy fields. The overall dimensions and specifications of tractor driven combine harvester are furnished in Table 1 and Plate 1. The treatments involved harvesting the seed crop using combine harvester at four different stages at the time of maturity *viz.,* at physiological maturity stage (T_1), 2 days after physiological maturity stage (T_2), 4 days after physiological maturity stage (T_3) and 6 days after physiological maturity stage (T_4). At each maturity stage

Plate 1. Combine harvester harvesting the seed crop.

the seed moisture was measured at the time of harvesting (Table 2). The experiment was designed using a Factorial completely randomized design (FCRD). The physical parameters *viz.,* splits or cracked in seed coat, visible broken seed (%), visible dehusked seeds (%), husk and kernel (%), seed to husk ratio, seed hardness test (kgf), biochemical parameters of electrical conductivity (dsm^{-1}) test were carried out. The mechanical damage assessed through ferric chloride test and TZ test and physiological parameters like germination (%), root length (cm), shoot length (cm), dry matter production (g $seedlings^{-10}$) and vigour index.

Moisture content (%)

Moisture content of the seed was analysed in a hot air oven maintained at 130 °C for2 hr and it is expressed in percentage on wet basis (9). It can be calculated using the formula,

$$\text{Moisture content (\%)} = \frac{M_2 - M_3}{M_2 - M_1} \times 100 \qquad \text{(Eqn.1)}$$

Where, M_1 = Weight of the bottle (g), M_2 = Weight of the bottle with sample before drying (g) and M_3 = Weight of the bottle with sample after drying (g)

Physical observations

Visual observation for splits or cracks in seed coat

Eight replicates of 5 g seeds were randomly selected, examined under purity work board where the damaged or split seeds were recorded and weighed, expressed in percentage. It was calculated based on the following formula (10).

Table 1. The overall dimensions and specifications of tractor driven combine harvester

S.No.	Particulars	Specification
1.	Hp	55
2.	Machine weight (kg)	6030 Approx
3.	Wheels	Rear wheel 6-50-20
4.	Number of straw walker	5
5.	Cutting capacity (acr/hr)	Paddy 1-1.25
6.	Overall dimension transport (mm)	Length: 10650, Width: 2888, Height: 4010
7.	Overall dimension working (mm)	Length: 7600, Width: 4884, Height 3410
8.	Peripheral speed of threshing drum (ms^{-1})	22-25
9.	Inlet threshing clearance (mm)	12-16
10.	Outlet threshing clearance (mm)	9-12
11.	Upper grain sieve (mm)	10-12
12.	Lower sieve (mm)	6-8
13.	Angular velocity of the fan shaft (ms^{-1})	30
14.	Effective cutting width (mm)	3520
15.	Blower type	Centrifugal

Table 2. Effect of seed physiological maturity and combine harvesting on seed moisture content (%) of rice varieties

Treatments / Rice variety	Seed moisture content (%)				
	T_1	T_2	T_3	T_4	Mean
TRY 3	27.2 (31.4)	24.8 (29.9)	22.5 (28.3)	19.7 (26.4)	23.6 (29.0)
CO (R) 50	26.3 (30.9)	23.8 (29.2)	20.6 (26.1)	18.6 (25.6)	22.3 (28.2)
ADT 54	26.5 (30.1)	25.2 (30.1)	23.3 (28.9)	19.3 (28.9)	23.6 (29.0)
Mean	26.7 (31.1)	24.6 (29.7)	22.1 (29.7)	19.2 (28.1)	23.2 (28.8)
	V		T		V×T
SEd	0.234		0.482		0.467
CD (P=0.05)	0.270		0.557		NS

Figures in parenthesis indicate arc-sine values. T_1 - At physiological maturity, T_2 - Two days after physiological maturity, T_3 - Four days after physiological maturity and T_4 - Six days after physiological maturity.

$$\text{Seed coat damaged seed \%} = \frac{\text{Seed coat damaged seeds (g)}}{\text{Total quantity of seed}} \times 100 \quad \text{(Eqn.2)}$$

Visible broken seed percentage (%)

Eight replicates of 5 g seeds were analysed manually visual and calculated expressed in percentage. It was calculated using the following formula (10).

$$\text{Visible broken seed percentage (\%)} = \frac{\text{Broken seeds (g)}}{\text{Total quantity of seeds (g)}} \times 100 \quad \text{(Eqn.3)}$$

Visible dehusked seeds (%)

Eight replication of 5 g dehusked seeds were examined visually to the naked eyes were separated from the total final seeds obtained after threshing.

$$\text{Visible dehusked seeds (\%)} = \frac{\text{Dehusked seeds (g)}}{\text{Total quantity of seeds (g)}} \times 100 \quad \text{(Eqn.4)}$$

Husk and Kernel percentage

Eight replicates of 5 g seeds were assessed to separate the husk and kernel individually without any barrier damage.

$$\text{Husk (\%)} = \frac{\text{Weight of Husk (g)}}{\text{Total quantity of seeds (g)}} \times 100 \quad \text{(Eqn.5)}$$

$$\text{Kernel (\%)} = \frac{\text{Weight of Kernel (g)}}{\text{Total quantity of seeds (g)}} \times 100 \quad \text{(Eqn.6)}$$

Seed to husk ratio

Eight replicates of 100 seeds were randomly collected for each variety, husk and seeds were separated manually and their respective weights were recorded in a sensitive electronic balance in gram. The seed to husk ratio was calculated based on mean weight.

Seed hardness test (Kgf)

The hardness of rice seeds was tested using a texture profile analyser (TAXT plus) at Department of Processing and Food Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Kumulur. To determine the seed resistance to mechanical force, a single compression force was applied to compress an individual rice seed equipped with a spherical stainless probe. Each rice seed was positioned on the test platform and the probe was lowered to compress the seed at a constant speed and return it to its original position. The force required to crush the seed was recorded as the peak force in kgf (11).

Electrical conductivity (dsm^{-1})

The seeds of different rice varieties at various physiological maturity stages of 25 seeds were taken and immersed in 25 ml of distilled water for 16 hrs. The solutions were agitated slightly and electrical conductivity was measured using a digital conductivity meter (12).

Physiological observation

The different physiological maturity of harvested seeds were tested in roll towel paper method at a temperature of 25 ± 2 °C and 95 ± 3 % relative humidity (RH) with the germination period of 14 days (9). Shoot length (cm), root length (cm), dry matter production (g $seedlings^{-10}$), vigour index (13) and electrical conductivity (12) were recorded.

Germination test

Four replicates of 100 seeds were tested for germination and the results were expressed as percentage (9). Ten seedlings from each replication were randomly taken and root and shoot lengths were measured. The seedlings were then oven dried at 85 °C for 24 hrs and weighed (13).

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds sown}} \times 100 \quad \text{(Eqn.7)}$$

$$\text{Vigour Index} = \text{Germination (\%)} \times \text{Total seedling length (cm)} \quad \text{(Eqn.8)}$$

Chemical method

Ferric chloride

Mechanical damage of the seed was detected using the ferric chloride test as described by (14). The seeds from different maturity stages were soaked in 20 % ferric chloride ($FeCl_3$) solution for 15 min interval, with the appearance of black colour indicating the seed damage. It can be expressed as percentage and calculated using the formula.

$$\text{Mechanical damage (\%)} = \frac{\text{Total number of black colour stained seeds counted after conduct of test}}{\text{Total number of seeds kept for conduct of test}} \times 100 \quad \text{(Eqn.9)}$$

Viability (%)

The tetrazolium test (TZ) is a biochemical test that provides a rapid assessment of seed germination potential and viability, that distinguishes live from dead seeds based on the activity of respiration enzymes, with results expressed as percentage (14-16). For this test, 75 seeds harvested at different maturity stages were soaked in water for 16 hrs, then immersed in 1 % triphenyl tetrazolium chloride (TTC) solution for 4 hrs at 30 °C. After the solution was drained, fully stained embryos indicated viable seeds, showing a red coloured compound called formazan.

Statistical analysis

The data were examined using the F-test of significance, as described by (17). Prior to analysis, the percentage data were transformed to angular (arc-sine) values whenever necessary. The critical differences (CD) were calculated at the 5 % probability level.

Results and Discussions

Moisture content (%)

The rice varieties were harvested using combine harvester at varying moisture content across different physiological maturity stages with various moisture content from 19.2 % to 26.6 %. The moisture content at different physiological stages T_1, T_2, T_3 and T_4, obtained as 26.6, 24.6, 22.1 and 19.2 % across the varieties 23.6, 22.3 and 23.6 % in TRY 3, CO (R) 50 and ADT 54 respectively irrespective of the interactions studied (Table 2). Harvesting the *Brassica napus* seed at 20 % optimum moisture content using combine harvester led to reduction in seed loss and damage (18, 19), whereas similar trend was observed in rapeseed harvesting the moisture between 25-30 % (20).

Physical observations

Visible broken seed percentage (%)

The seed harvested at physiological maturity stage, two days, four days and six days after showed 0.21, 0.92 and 0.83 and 0.98 % across the varieties V_1, V_2 and V_3 were 0.29, 1.23 and 0.70 % respectively (Table 3). The broken seed reduction in seed breakage can be attributed to harvesting the crop at an optimal moisture content of 23.55 %, which helps minimize breakage as moisture increases in rice (18, 19, 5) in soybean (20) and sunn hemp (21). Broken seed impair their germination ability of cereals (22) and increase in kernel breakage and a decrease in seed germination due to decrease in forward speed, increase in cylinder rotational speed and decrease in clearance between cylinder and concave in wheat (23), if moisture content decreased too low, then broken seed increased in rice (5).

Visible dehusked seeds (%)

Harvesting the different rice varieties at physiological maturity stage, two days, four days and six days after maturity stage recorded 0.27, 0.40, 0.63 and 1.31 % respectively (Table 4). The highest dehusked seed was recorded at six days after physiological maturity (0.65 %), while the lowest was noted at physiological maturity stages (0.27 %) irrespective of the varieties studied. This attributed due to the percentage of dehusked seeds should optimum when harvesting at physiological maturity when the husk adheres tightly to the grain because of ideal moisture content. As moisture decreases or the seed dry the husk loosens and making it easier to remove with more maximum damage (21).

Husk and kernel percentage

The husk and kernel percentage of rice varieties revealed that the mean percentage of husk and kernel were 22.51, 21.76 and 21.50 % and 77.33, 77.32 and 77.12 % respectively (Table 5, 6). This corresponds with a moisture content from 26.65 % to 23.15 %. The result suggest that optimum moisture content improves intact kernel % with minimum husk loss. Conversely delaying the harvest at low moisture results in brittleness and higher husk loss. Higher the moisture content causes the husk is adhere more firmly and make not easily split in rice (24).

Table 3. Effect of seed physiological maturity and combine harvesting on broken seed (%) of rice varieties

Treatments / Rice variety	Broken seed (%)				
	T_1	**T_2**	**T_3**	**T_4**	**Mean**
TRY 3	0.16 (2.29)	0.50 (3.14)	0.20 (7.08)	0.30 (4.21)	0.29 (3.09)
CO (R) 50	0.42 (4.05)	1.71 (3.71)	1.52 (6.42)	1.25 (5.07)	1.23 (6.37)
ADT 54	0.06 (2.56)	0.54 (7.51)	0.78 (1.40)	1.40 (6.79)	0.70 (4.80)
Mean	0.21 (2.63)	0.92 (5.50)	0.83 (5.50)	0.98 (5.23	0.74 (4.93)
	V		**T**		**V×T**
SEd	0.007		0.008		0.014
CD (P=0.05)	0.015		0.017		0.030

Figures in parenthesis indicate arcsine values. **T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

Table 4. Effect of seed physiological maturity and combine harvesting on dehusked seed (%) of rice varieties

Rice variety \ Treatments	Dehusked seed (%)				
	T_1	T_2	T_3	T_4	Mean
TRY 3	0.20 (2.56)	0.30 (3.14)	0.60 (4.44)	1.30 (6.55)	0.60 (4.44)
CO (R) 50	0.30 (3.14)	0.40 (3.62)	0.50 (4.05)	1.35 (6.55)	0.64 (4.59)
ADT 54	0.30 (3.14)	0.50 (4.05)	0.80 (5.13)	1.28 (6.54)	0.72 (4.87)
Mean	0.27 (2.98)	0.40 (3.63)	0.63 (6.55)	1.31 (4.62)	0.65 (4.62)
	V		T		V×T
SE	0.007		0.009		0.015
CD (P=0.05)	0.016		0.018		0.032

Figures in parenthesis indicate arcsine values. **T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after Physiological maturity.

Table 5. Effect of seed physiological maturity and combine harvesting on husk (%) of rice varieties

Rice variety \ Treatments	Husk (%)				
	T_1	T_2	T_3	T_4	Mean
TRY 3	23.16 (28.77)	22.6 (28.38)	22.09 (28.03)	22.2 (28.11)	22.51 (28.32)
CO (R) 50	22.04 (28.00)	21.68 (27.75)	21.41 (27.56)	21.91 (27.91)	21.76 (27.81)
ADT 54	21.69 (27.76)	21.55 (27.66)	21.45 (27.59)	21.30 (27.48)	21.50 (27.62)
Mean	22.30 (28.18)	21.94 (27.93)	21.65 (27.83)	21.80 (27.93)	21.92 (27.92)
	V		T		V×T
SEd	0.254		0.294		0.509
CD (P=0.05)	0.525		NS		NS

Figures in parenthesis indicate arcsine values. **T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

Table 6. Effect of seed physiological maturity and combine harvesting on kernel (%) of rice varieties

Rice variety \ Treatments	Kernel (%)				
	T_1	T_2	T_3	T_4	Mean
TRY 3	76.65 (61.10)	77.46 (61.65)	77.55 (61.72)	77.67 (61.80)	77.33 (61.57)
CO (R) 50	76.61 (61.08)	76.98 (61.33)	77.84 (6.92)	77.83 (61.91)	77.32 (61.56)
ADT 54	76.50 (61.00)	76.78 (61.19)	77.52 (61.70)	77.66 (61.79)	77.12 (61.42)
Mean	76.59 (61.06)	77.07 (61.39)	77.64 (61.83)	77.72 (61.39)	77.25 (61.51)
	V		T		V×T
SEd	0.725		0.837		1.450
CD (P=0.05)	NS		NS		NS

Figures in parenthesis indicate arcsine values. **T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

Seed to husk ratio

The harvested seeds of V_1, V_2 and V_3 were 3.42, 3.55 and 3.59 with different maturity stages of T_1, T_2, T_3 and T_4 were 3.44, 3.51, 3.58 and 3.54 respectively with irrespective interaction between the variables were not statistically significant (Table 7). The higher content, the husk is attached to the kernel (24, 25). Lower the moisture loss can cause the husk to become more fragile or tightly bound due to moisture loss, resulting in inefficient separation (21).

Seed hardness test (kgf)

The results of the hardness of the seed harvested with combine harvester with different moisture content revealed that the higher the force exists at maximum T_1 (16.13) and further subsequently decreased at T_4 (14.43) kgf (Table 8). The highest hardness has well established seeds, whereas the lowest hardness has medium sized seeds (26).

Electrical conductivity (dsm^{-1})

Seeds harvested and determined for various physiological maturity stages of electrical conductivity were evaluated. The EC values are 0.07, 0.08, 0.09 and 0.09 dsm^{-1} resulted at physiological, two days, four days and six days after maturity stages respectively irrespective of the varieties studied (Table 9). Lower the leachates at physiological maturity and higher at six days after physiological maturity stages due to quenching of free radicals, which restores membrane integrity (27).

Table 7. Effect of seed physiological maturity and combine harvesting on seed to husk ratio of rice varieties

Treatments / Rice variety	Seed to husk ratio				
	T_1	**T_2**	**T_3**	**T_4**	**Mean**
TRY 3	3.31	3.43	3.51	3.44	3.42
CO (R) 50	3.48	3.55	3.63	3.55	3.55
ADT 54	3.53	3.56	3.61	3.64	3.59
Mean	3.44	3.51	3.58	3.54	3.52
	V		**T**		**V×T**
SEd	0.041		0.048		0.083
CD (P=0.05)	0.085		NS		NS

T_1 - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity

Table 8. Effect of seed physiological maturity and combine harvesting on seed hardness (Kgf) of rice varieties

Treatments / Rice variety	Seed hardness				
	T_1	**T_2**	**T_3**	**T_4**	**Mean**
TRY 3	16.17	12.90	14.81	15.52	14.85
CO (R) 50	18.40	16.57	10.84	12.92	14.68
ADT 54	13.81	14.53	16.33	14.85	14.88
Mean	16.13	14.67	13.99	14.43	14.80
	V		**T**		**V×T**
SEd	0.148		0.170		0.295
CD (P=0.05)	NS		0.352		0.609

T_1 - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

Table 9. Effect of seed physiological maturity and combine harvesting on electrical conductivity (dsm^{-1}) of rice varieties

Treatments / Rice variety	Electrical conductivity (dsm^{-1})				
	T_1	**T_2**	**T_3**	**T_4**	**Mean**
TRY 3	0.07	0.07	0.08	0.08	0.08
CO (R) 50	0.10	0.11	0.12	0.13	0.12
ADT 54	0.06	0.07	0.07	0.07	0.07
Mean	0.08	0.08	0.09	0.09	0.09
	V		**T**		**V×T**
SEd	0.0031		0.0035		0.0061
CD (P=0.05)	0.0062		NS		0.0124

T_1 - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity

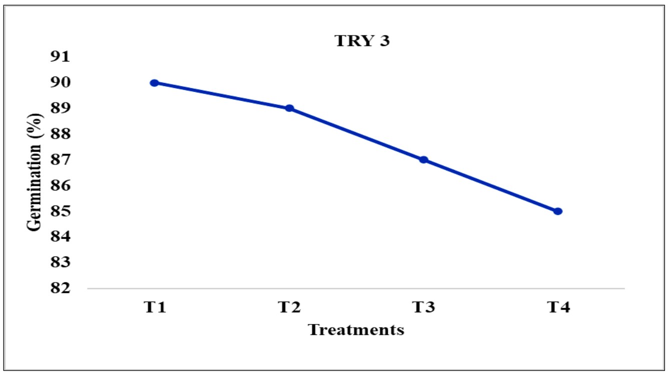
Physiological observations

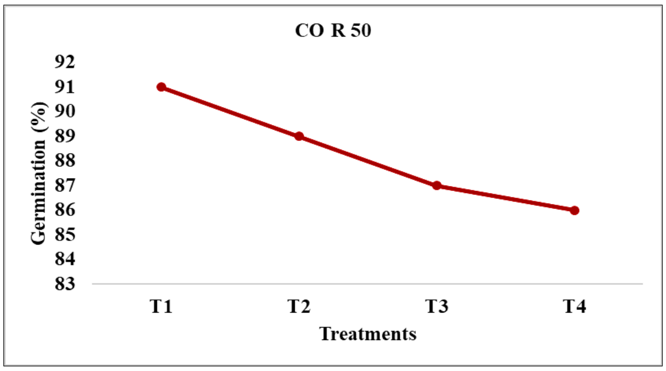
Germination%

The germination resulted maximum at physiological maturity stage (91 %), followed by two days (90 %), four days (87 %) and six days after physiological maturity stage (86 %) (Fig. 1). The six days after physiological maturity stage gave more than 80 % of germination irrespective of the variety studied. This satisfies the Indian Minimum Seed Certification Standards (IMSCS) of 80 % seed germination. Soybean seeds harvested by combine at lower rpm significantly improve germination and feeding rate is an important factor for reducing the seed losses (28, 29). Harvesting the seed crop at post physiological maturity stage can cause field weathering, seed deterioration, including increased seed cracking, moisture fluctuations, fungal infections and biochemical changes that reduced viability and lower storage longevity due to ageing process.

Seedling length (cm)

The seeds harvested at different maturity stages of root and shoot length resulted T_1, T_2, T_3 and T_4 were 24.6 cm, 23.5 cm, 23.1 cm and 22.7 cm across the varieties of V_1, V_2 and V_3 of 24.4 cm, 23.3 cm and 22.7 cm with shoot length of 13.1 cm, 11.5 cm, 11.3 cm and 10.4 cm respectively (Table 10). In Daincha, the highest shoot length 7.37 cm recorded in harvesting and threshing method followed by combine harvester 9.18 cm and the lowest shoot length was recorded in seeds harvested and threshed by manual method 5.28 cm (33). Higher the dry matter production at V_1 0.164 (g/10 seedling) enhance with higher vigour index 3347 (V_1) (Table 11). This revealed that sunn hemp crop harvested using by combine recorded 89 % of germination with highest shoot length (15.1 cm) with dry matter recorded of 0.182 g/ seedling (24). Similar trend resulted in daincha (30).





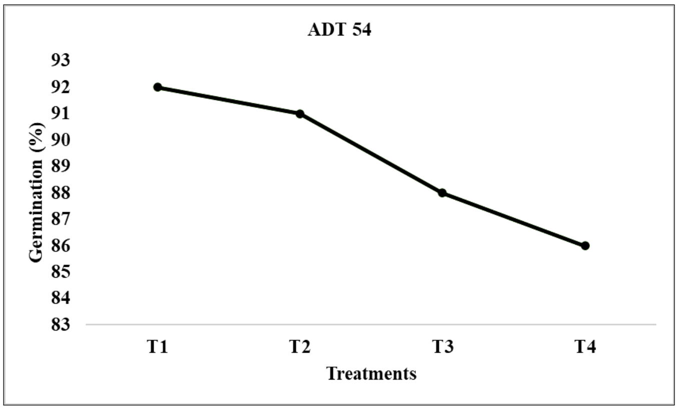


Fig. 1. Effect of seed physiological maturity and combine harvesting on germination (%) of rice varieties (**T_1** - at physiological maturity stage, **T_2** - Two days after physiological maturity stage,**T_3** - Four days after physiological maturity stage, **T_4** - Six days after physiological maturity stage).

Table 10. Effect of seed physiological maturity and combine harvesting on seedling growth of rice varieties

Treatments / Rice variety	Root length (cm)					Shoot length (cm)				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
TRY 3	25.1	24.8	24.5	23.2	24.4	14.5	13.1	13.8	13.5	13.7
CO (R) 50	24.1	23.5	22.9	22.9	23.3	13.8	11.4	11.3	9.2	11.4
ADT 54	24.6	22.2	21.8	22.1	22.7	10.9	9.8	8.7	8.5	9.51
Mean	24.58	23.50	23.08	22.74	23.47	13.08	11.46	11.30	10.38	11.55
	V	T	V×T			V	T	V×T		
SEd	0.332	0.384	0.665			0.141	0.163	0.283		
CD (P=0.05)	0.935	1.080	NS			0.292	0.337	0.583		

T_1 - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity

Table 11. Effect of seed physiological maturity and combine harvesting on dry matter production (g seedling^{-10}) and vigour index of rice varieties

Treatments / Rice variety	Dry matter production (g seedling^{-10})					Vigour index				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
TRY 3	0.166	0.165	0.163	0.160	0.164	3557	3374	3338	3120	3347
CO (R) 50	0.146	0.139	0.137	0.104	0.132	3226	3106	3193	2753	3070
ADT 54	0.137	0.104	0.100	0.099	0.110	3266	2917	2670	2655	2877
Mean	0.150	0.136	0.133	0.121	0.135	3350	3132	3067	2843	3098
	V	T	V×T			V	T	V×T		
SEd	0.002	0.002	0.003			36.88	42.58	73.760		
CD (P=0.05)	0.003	0.004	0.007			76.12	87.89	152.23		

T_1 - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

Detection of mechanical damage

Ferric chloride (%)

Seeds were harvested at different stages of various varieties and assessed for mechanical damage with physical method like visual observation of splits, cracked or damaged seeds and chemical method using $FeCl_3$ and TZ test were studied. The mechanical damage of ferric chloride test was examined to harvest at physiological maturity stage, two days, four days and six days after physiological maturity stages recorded 7.7 %, 8.1 %, 8.6 % and 9.2 % respectively (Table 12).

Table 12. Effect of seed physiological maturity and combine harvesting on Mechanical damage (%) of rice varieties

Treatments / Rice variety	Mechanical damage (%)									
	Physical method					Chemical method				
	T_1	T_2	T_3	T_4	Mean	T_1	T_2	T_3	T_4	Mean
TRY 3 (V1)	3.6 (10.94)	5.8 (13.94)	7.2 (15.56)	8.4 (16.85)	6.2 (14.42)	6.7 (15.00)	7.7 (16.11)	7.9 (16.32)	8.1 (16.53)	7.6(16.00)
CO (R) 50 (V2)	5.2 (13.18)	6.5 (14.77)	6.8 (15.12)	7.4 (15.78)	6.5 (14.77)	7.7 (16.11)	8.3 (16.74)	8.5 (16.95)	9.2 (17.65)	8.4 (16.84)
ADT 54 (V3)	6.4 (14.65)	8.5 (16.95)	9.0 (17.46)	9.2 (17.66)	8.3 (16.74)	8.7 (17.15)	8.3 (16.74)	9.4 (17.85)	10.4 (18.81)	9.2 (17.66)
Mean	5.1 (13.05)	6.9 (15.23)	7.7 (16.11)	8.3 (15.34)	7.0 (16.11)	7.7 (16.11)	8.1 (1.053)	8.6 (17.05)	9.2 (16.85)	8.4 (17.05)
	V		T		V×T	V		T		V×T
SEd	0.078		0.091		0.157	0.105		0.122		0.211
CD (P=0.05)	0.162		0.187		0.324	0.217		0.251		0.435

Figures in parenthesis indicate arcsine values.**T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity.

From the results it was concluded that the physical parameters show that with increasing moisture correlates with a reduction in mechanical losses such as cracking and seed breakage in rice with similar results (21). In maize higher moisture during husking and threshing process led to increased susceptibility to the mechanical damage (31). In sunn hemp minimum mechanical damage of 4 % was observed manual harvesting and tractor treading which attribute flat seed surface and hard seed coat provide resistance to mechanical impact (24). The proper adjustment of threshing machines is essential for minimizing mechanical damage and achieving high quality seeds in rice (21). Increasing the rotational speed of threshing mechanism in soybean causes higher seed damage (32). The grain loss can be minimized with higher moisture content with increased cylinder speed in soybean (32).

Viability

The results of TZ test showed that the maximum viability at physiological maturity stage 91 %, were the lowest at six days after physiological maturity 86 % (Table 13). This resulted that higher germination enhance with maximum viability in rice (6). The six days after maturity stage exhibited low viability, due to the early signals of physiological deterioration, such as decreased antioxidant activity or breakdown of cellular components (33).

Conclusion

Rice seed crop harvested using combine harvester with different moisture content at physiological maturity, two days, four days and six days after physiological maturity revealed that germination percentage was not that much variation between at physiological maturity and six days after physiological maturity irrespective of the varieties studied. Therefore, the seed crop harvested with combine harvester either at physiological maturity or up to six days after physiological maturity stage are used as seed material without losing its viability and seedling vigour. Besides that, seed crop harvested using combine harvester revealed minimum mechanical damage at physiological maturity stage to six days after physiological maturity stage. Hence, it is recommended that harvest the rice seed crop through combine harvester in the moisture range of 19 to 27 % at physiological maturity stage or six days after physiological maturity it maintain more than 80 % germination irrespective of the varieties studied and satisfied the Indian Minimum Seed Certification Standards.

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Table 13. Effect of seed physiological maturity and combine harvesting on viability (%) of rice varieties

Treatments / Rice variety	Viability (%)				
	T_1	T_2	T_3	T_4	Mean
TRY 3	92 (73.57)	90 (71.57)	89 (70.63)	87 (68.87)	90 (71.57)
CO (R) 50	90 (71.57)	89 (70.63)	87 (68.87)	86 (68.03)	88 (69.73)
ADT 54	91 (72.54)	89 (70.63)	88 (69.73)	86 (68.03)	89 (70.63)
Mean	91 (72.54)	89 (70.63)	88 (69.73)	86(68.03)	89 (70.63)
	V		T		V×T
SEd	0.998		1.153		1.997
CD (P=0.05)	NS		2.379		NS

Figures in parenthesis indicate arcsine values. **T_1** - At physiological maturity, **T_2** - Two days after physiological maturity, **T_3** - Four days after physiological maturity and **T_4** - Six days after physiological maturity

Authors' contributions

RJC and PM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BS and PR managed the analyses of the study. Authors SDS and VM managed the literature searches. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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