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REVIEW ARTICLE

Impact of harvesting and threshing methods of rice: A comprehensive review on seed quality and storage behaviour

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Abstract

Rice, being a staple food produced on a large scale production accounts for more than 135 million tonnes in the year 2023. Harvesting and threshing operations are important and influential processes on quality, quantity and production cost in rice. Harvesting the rice crops using sickles is a common method is a labour-intensive process that causes labour shortages and often delay seed losses, grain loss due to over maturity, inefficient techniques may cause seed quality deterioration, shattering of seeds, post-harvest losses of 30 % and mechanical damage. Threshing, cleaning and winnowing causes various problems with post harvest losses, seed breakage, improper removal of stones, debris, chaffy materials in the paddy seed. To overcome these techniques harvesting and threshing can be done by mechanized harvesting using combine harvester offers an alternate solution. Combine harvester allows timely harvesting while minimizing losses. However, improper adjustment in machine harvesting can cause mechanical damage with reduced seed quality. These factors impact on seed yield as well as storage, inadequate drying, seed spillage and viability loss, which results reduction in a germination potential. The ideal moisture content of 20-25 % for harvesting rice is usually too high for safe storage with low mechanical losses. Additionally, employing hermetic storage techniques and controlled drying processes further enhance seed longevity and quality by preventing microbial contamination, pest and insect damage. Implementing these improved methods can significantly reduce post harvest losses, ensure better seed quality and improve the storability of rice which address the growing demand for seed production over traditional methods.

Keywords: combine harvester; harvesting and threshing methods; moisture content; post-harvest loss; rice; seed germination; seed storage

Introduction

Rice serves as the staple food for more than half of the world's population. In India, rice is cultivated across an area of 47.83 million hectares, producing 135.75 million tonnes with productivity of 2838 $kgha^{-1}$ (1). Harvesting is an important process in rice production, as it is often associated with significant yield losses (2). Rice harvest losses range from 5 to 16 % due to delayed harvesting and shattering. Consequently, timely harvesting is crucial as it significantly affects both yield and quality (3, 4). Harvesting rice using traditional method by sickles is a labour intensive and prolonged process (5, 6). The quality and longevity of the rice crop are determined by the post-harvest handling during the period of harvesting and threshing (7). Post-harvest losses, including up to 30 % yield reduction and mechanical damage, are often attributed to delays in manual harvesting (8). Premature or early harvesting results in seed breakage, immature or ill-filled grains and qualitative and quantitative losses in rice and while late harvesting leads to shattering loss (9, 10). Harvesting the crop below 20 % moisture content cause immature seeds (11), chaffy seeds (12), shattering losses (13), increased mechanical damages (14), seed contamination (15), mold growth (16), which prone to diseases (10) and insects (8), that are selective to attack the embryo cause great losses in germination as compared to others (17).

Storage of rice with moisture levels exceeding 14 % makes seeds vulnerable to microbial deterioration and mycotoxin contamination (18), broken kernels (19), hence timely drying to 12-14 % moisture content soon after threshing prevents viability losses, susceptible to mold, fungi and insect infestations during storage (20). Too rapid drying can cause fissures and cracks leading to broken rice (21) and low moisture make grains brittle and prone to breakage which could contribute to the viability and longevity during storage (22). Seed viability and vigour gradually decline during storage, which result in deterioration of aging, accelerated by mechanical damage during post-harvest handling (14).

To overcome these factors, harvest the rice crop at optimum moisture content around 20-25 % and 80 % of the grain turned to straw yellow colour and enhanced with the techniques using multipurpose machine, a combine harvester which combines all the operations into single action like reaping, threshing and winnowing of crop seed (23, 24) as shown in Fig. 1. Using this method, enables farmers to save time, reduce the drudgery, labour and costs, while ultimately improves the output and profit quality parameters and storage behaviour effects on seed harvesting, losses and viability over time (25). It is worked throughout the field operations, which involves increase in production and to minimize the human work and requires about 150-200 man-h ha^{-1} for harvesting of rice alone (26). Minimum labour work, require low costs and reduce mechanical damage to seeds (25), seed loss, which aims for the best seed quality and production (27). The process not only focus on maximizing the yield but also preserves the seeds integrity, deterioration that could affect the storage viability, which aims at improvement in seed characteristics (28). By using this harvester, reduction of 10 % post-harvest losses with high germination of 97 % could be obtained (29). It also helps to avoid mechanical stress and injury (30). Manual rice harvesting is labour intensive and delays can lead to significant yield losses. Timely harvesting is crucial to minimize these losses and maintain crop quality (4), mechanical damages to the seed coat and increase the seed deterioration during storage (25).

The objective of this review is to focus on evaluating the various harvesting and threshing methods of rice and assess their impact on the seed quality and storage. This study is distinguishing on the effectiveness of manual and mechanical harvesting methods predominantly the use of combine harvesters, which elucidates how post-harvest loss reduction, seed germination and storage behaviour. The findings also say harvesting the rice crop at ideal moisture content between 20-25 % and use hermetic storage techniques for the storage conditions, which maintains seed viability. These insights contribute to the better understanding of rice harvesting and provide valuable management for enhancing seed production.

Harvesting and threshing methods

Harvesting and threshing methods are important processes in rice seed production, that influence overall post-harvest losses and affect seed quality (31, 32). Proper harvesting and threshing methods are essential for maximizing seed quality, viability and germination, ensuring effective planting material for future rice crops (15).

Harvesting

Harvesting is defined as the separation of the primary or economic product from a crop cutting, picking, plucking, digging or a combination of these operations comes under harvesting (33, 34). In rice cultivation, harvesting is an important operation, that includes cutting the plants, bundling them, transporting the bundles and threshing. These operations are typically carried out manually or with small scale equipment at different stages. Though, it is a quiet and prolonged process, resulted in delaying of harvest. The early harvest cause to premature germination, shrivelled seeds with low viability and birds attack (35). Late harvesting resulted in seed shattering and wastage. Timely harvesting ensures that seeds are fully developed and ripened, achieving optimum dry matter accumulation (36).

Threshing

Seed processing is an essential element of any organized seed production aimed at improving seed quality (28). The purpose of the threshing process is to separate the seeds from the panicles. This process can be carried out using both manual and mechanical methods. Manual threshing involves the separation of seeds by beating the panicles against hard surfaces, trampling or by animal power (37). Mechanical threshing involves motorized power on beating arms of the axial flow thresher (23). Grain spilling, inadequate separation of grain and chaff and grain breakage are some of the major causes of losses during the threshing process (37). Thresher is a machine also used to separate the seeds from the harvested crop with minimum damage (38). It is also employed with equipment such as combine harvester to accelerate the process, however with proper machine adjustments can reduce seed breakage and improve seed germination (39).

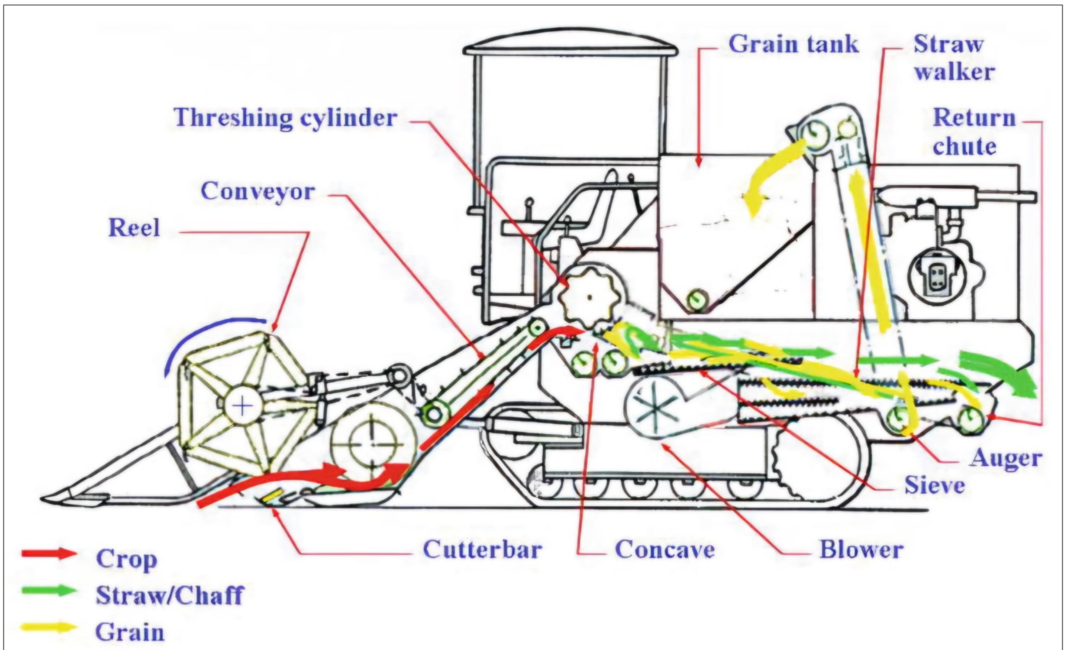

Fig. 1. Combine harvester (23).

Combine harvester

The combine harvester is a machine that "combines" the tasks of harvesting, threshing and cleaning into single process. This trend is driven by a significant shortage of labour and the consequent rise in harvesting costs, making the utilization of combines economically appealing in Fig. 1 (24).

Classification of harvesting systems

There are two methods of harvesting *viz.,* manual (traditional) and mechanical (thresher / combine harvester) method. The purpose of harvesting is to optimize production, reduce losses and prevent quality deterioration (23). Harvesting systems differ based on regional practices, utilizing various tools that range from traditional to semi-mechanized and fully mechanized methods (23). The diagrammatic representation and potential benefits of harvesting system in rice are illustrated in Fig. 2, 3.

Physiological maturity

Seed growth and physiological maturation are essential, as timely harvesting ensures the seeds maintain high viability and vigour. Harvesting rice seeds at physiological maturity stage ensures the production of high quality seeds with an extended shelf life. Physiological maturity is the stage at which the seed is fully developed and has reached its maximum dry weight and vigour (40). Seeds should be harvested at the right time, with optimal moisture content (23). After harvesting, the seeds are dried to reduce moisture content, preventing post-harvest losses due to microbial contamination and ensuring proper germination (7).

In rice, the seed development and maturity play a dynamic process controlled by environmental, physiological and genetic factors (41). Seed performance in the field or in storage, including germination behaviour, vigour characteristics and viability maintenance, are greatly influenced by the developmental stages (42, 43) as shown in Fig. 4.

Role of combine harvester on labour, time and manpower

Early harvesting causes immature and chaffy seeds, shattering losses resulting lower the quality and storability during maturity (44). Delayed harvesting resulted delays in sowing of next crops (45), due to manpower inaccessibility and increased seed or yield losses owing due to over maturity, which causes yield loss due to seed breakage and damage, seed deterioration leads to ageing, which impact on seed quality (44). Therefore, timely harvesting is required to avoid those mechanical damages, hence, to acknowledge these issues, the combine harvester, serves as a mechanized solution for preserving seed vigour and enhancing production (46), also assess with labour shortage and minimal seed damages (25). The combine harvester effect on time and cost savings over to traditional methods are provided below in Table 1.

Effect of physiological qualities using combine harvester

Seed germination

Rice productivity is significantly dependent on quality seeds with high germination rate (49). With the growing world population and increasing demand for rice, improving rice productivity and quality through advancements in harvesting and threshing is crucial (50). Therefore, production of high-quality seeds with superior germination capacity and potential storability is essential. This requires maintaining seed viability by adopting appropriate harvesting, threshing and processing protocols to avoid mechanical stress and injury (30). Grain damage and unthreshed grains affected by the threshing methods, which indicated that the method of threshing influences both germination rates and the storage life (51).

The paddy seeds harvested using various combine harvesters indicated that the Kubota combine harvester revealed that highest germination percentage of 97.06 %, with the lowest seed damage at 13 %, while the Agrotech combine harvester showed the lowest germination percentage among all the harvesters of 94.25 %, with highest seed damage

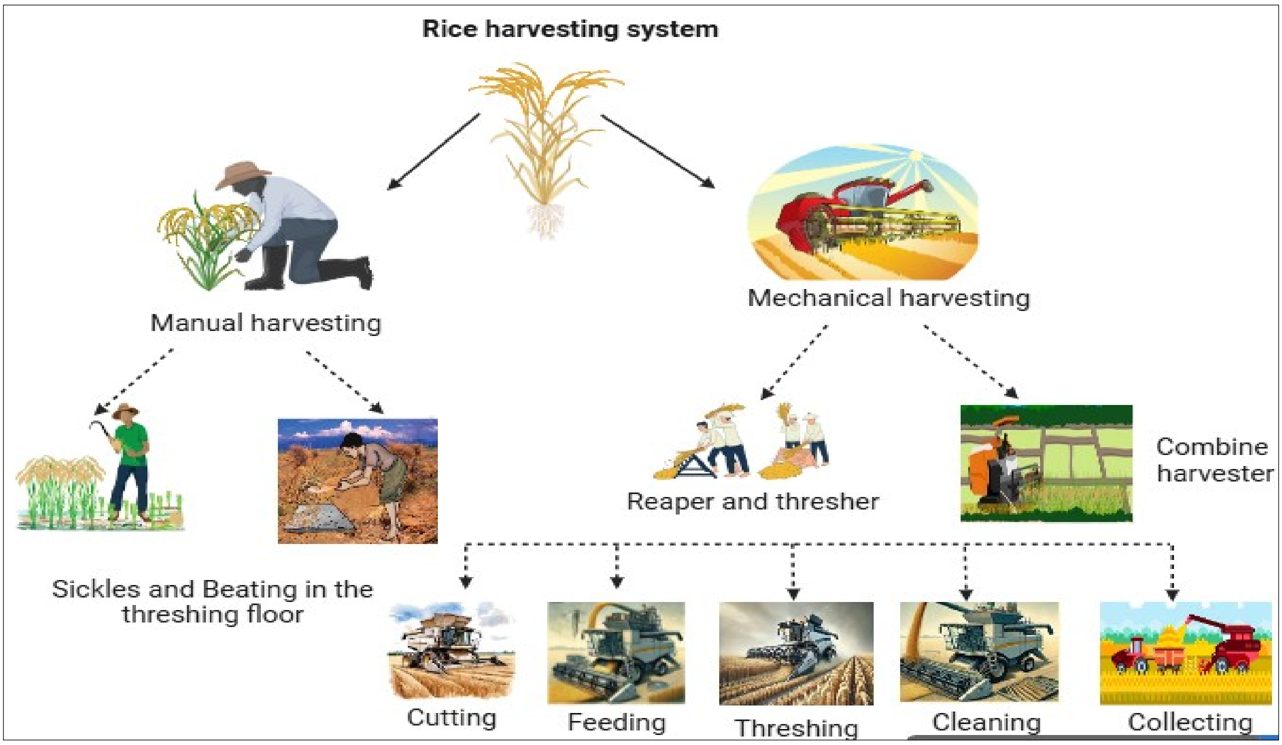

Fig. 2. Classification of harvesting systems.

Table 1. Comparative economic analysis of rice cultivation between conventional and combine harvester methods

S. No.	Particulars	Harvesting method		References
		Manual	Mechanical	
1.	Labour	280 man-h ha^{-1}	4 man-h ha^{-1}	(47)
2.	Costs	Rs. 10515 ha^{-1}	Rs. 5458 ha^{-1}	(48)
3.	Time	111.10 h ha^{-1}	3.64 h ha^{-1}	(4)

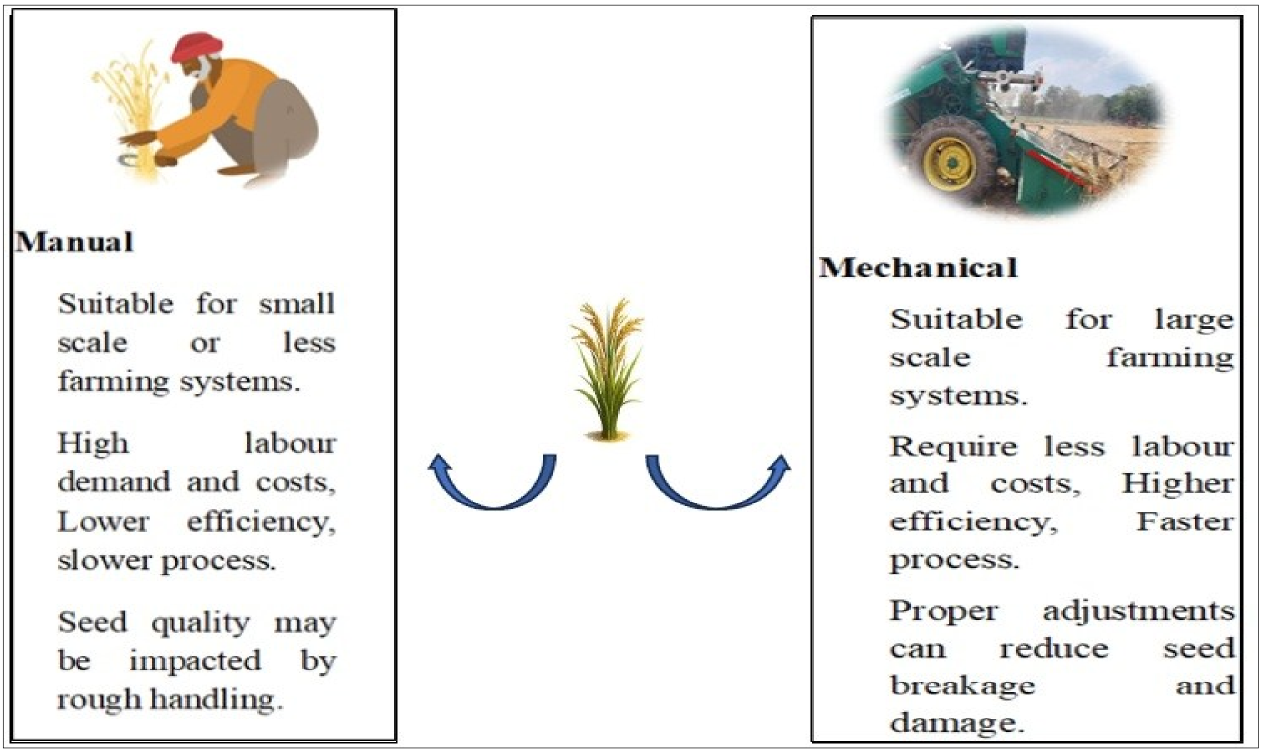

Fig. 3. Comparison of potential benefits of manual and mechanical harvesting methods in rice.

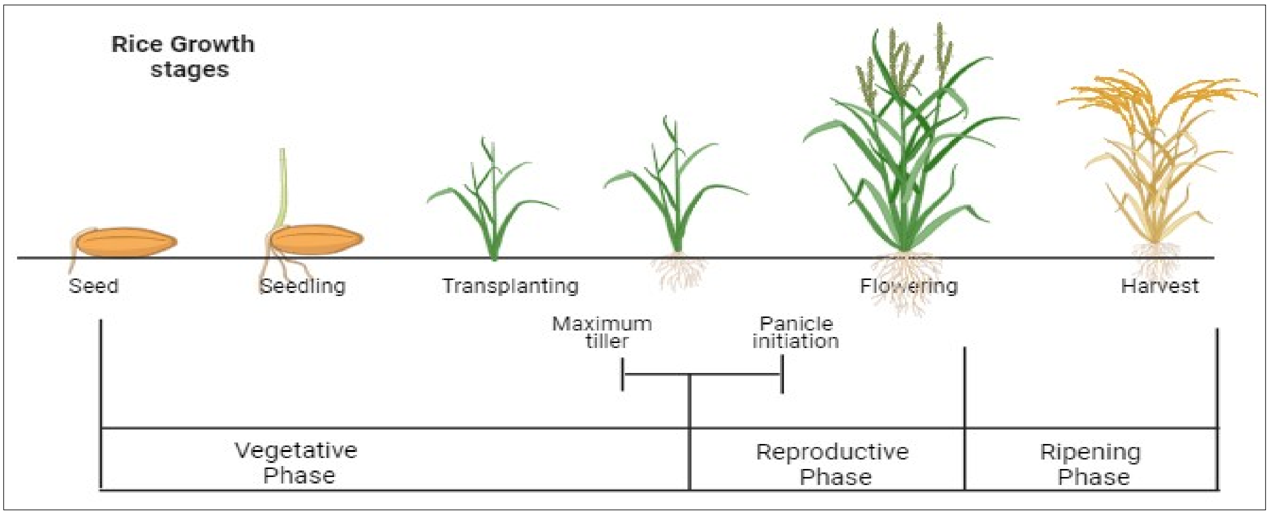

Fig. 4. Developmental stages of rice growth.

percentage of 24 % (Table 2.) (29). The study findings emphasized that the seed damage affects the reduction in seed germination. The occurrence of lowest damage seed samples showed higher germination. The study indicated that using a new or well-maintained combine harvester did not significantly affect the reduction in seed germination and mechanical damage. However, mechanical damage to seeds was found to occur during machine harvesting, leading to a decrease in seed germination percentage. The study further noted that the mechanical damage to seeds could increase over time due to the wear and tear of mechanical parts in machines used for an extended period without replacement. The results of the study were consistent with previous research (32).

Post-harvest operations significantly affect the handling, processing and seed storage. Physical damage incurred during post-harvest handling and threshing adversely affects the germination capacity and vigour of crop seeds, damaged seeds are prone to producing abnormal seedlings, exhibit reduced resistance to pests and diseases and have a short storage. Protecting seed quality is essential for improving crop quality and production. The primary challenge is to retain seed quality, as well as to develop better, more cost effective and dynamic ways for post-harvest handling and threshing the harvesting of seeds (52).

Table 2. Effect of different combine harvester on germination (%) and mechanical damages in rice

S. No.	Combine harvester	Crop	Germination (%)	Mechanical damage	References
1.	Class (Model Crop Tiger 40 Terra Trac)	Rice	96.83	14.21	(29)
2.	Kubota (Mode DC-68G)		97.16	13.42	
3.	Agrotech (Model 4R1040)		94.25	24.74	
4.	Mubota (Mode 4LZ-2.0)		95.74	18.46	
5.	Control		97.31	10.56	

The effect of reducing post-harvest losses on three threshing methods like stone, bambam (wooden box) and combine harvester on two varieties namely AGRA and Jasmine 85 on germination percentage. The Jasmine 85 shows highest germination (86.11 %) in threshing method used, while AGRA results lower germination (63.88 %) which attributed due to increased storage of carbohydrates in the endosperm of Jasmine 85 than AGRA in Table 3 (53). The lower germination occurred due to embryo of AGRA seeds dislodged. Whereas the dockage recorded higher in combine (0.41 %) than the stone (0.22 %) which may be due to the breakage of rice straws in combine. While the immature grains occur higher in AGRA (1.02 %) than Jasmine 85 (0.61 %) due to lowest seedling vigour, hence produced more maturation of seeds at Jasmine 85. The suitability of the threshing method depends on the variety, hence such information must be considered during the design and development of post-harvest equipment. The findings also relate with brown rice in Table 4 (54).

Seedling vigour

Seed vigour is an important seed quality parameter that must be evaluated to support germination and viability tests, to attain the performance of a seed lot in either field or storage conditions (43). Seed vigour is the sum of those properties, which determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence (55). Harvesting the rice seed using combine harvester resulted with minimum mechanical damage and showed no significant impact on seed germination and seedling vigour, regardless of the varieties examined (25).

The effect of harvesting and threshing procedures on seed quality in the rice cultivars CR 1009 Sub 1, IW Ponni and CO 51. The treatments consisted of manual harvesting and manual threshing, manual harvesting and mechanical threshing (axial flow thresher) and combine harvesting (with pneumatic wheel), which revealed that the germination and vigour index were highest in manually harvested and threshed seeds with 94 % and 3519 respectively followed by combine harvested seed with 91 % and 3255 and the lowest was found in manual harvesting and mechanical threshing with 94 % and 3519, respectively as shown in Table 5, due to fractured seed coat damage, indicating a decrease in seed vigour. The findings revealed that rice seeds harvested and threshed using manual methods or a combine harvester enriched the threshing efficiency, had no harmful impacts on germination and seedling vigour (56).

Storage

Storage is an essential component of seed programs, which primarily aims at keeping the high-quality standards of the seed from harvest to sowing for the succeeding seasons (57). The moisture content of the harvested seeds should be dried to 13 % for proper storage, if not dried properly, the seeds get deteriorated due to various factors, including temperature, moisture content, humidity, insect infestation, grain discoloration, weight loss or gain and nutrient depletion (58, 59) and infested with insects leads to damage (7). Packaging materials and storage time influence these factors. With the proper maintenance of packaging materials, quality will be retained throughout the season for improving the vigour and viability of stored seeds (60).

Rough rice grains harvested by the combine harvester with cylinder speed 1100-1700 mmin^{-1} and with moisture content at 16, 18, 20, 22 and 24 % and stored for 30 days at temperature of 23 °C, 28 °C and 32 °C. The samples containing less than 20 % moisture, showed no significant changes in moisture content during the storage period, whereas, in samples containing more than 20 % moisture, showed increase in moisture content at the later storage stages, when stored at temperatures ranging from 23 to 32 °C. When grains with 23.6 % moisture content were stored at temperatures of 23 °C to 32 °C and variable, they could only be safely stored for one day. Conversely, grains containing 18 % moisture harvested with less than 18.9 % moisture were stored at temperatures of 13 °C to 23 °C and variable, could be safely stored for 30 days without any deterioration in quality. The maximum safe storage duration of rough rice harvested by the combine was shorter than that of grains threshed by the self-feeding thresher, as the percentage of injured grains harvested using the combine was higher than that threshed by the self-feeding thresher (61).

Table 3. Effect of different threshing methods on germination (%) of paddy variety

S. No.	Threshing methods	Variety			Reference
		Germination (%)			
		AGRA	Jasmine 85	Mean	
1.	Combine	51.66	83.33	67.50	(53)
2.	Bambam	68.33	90.00	79.17	
3.	Stone	71.66	85.00	78.33	
	Mean	63.88	86.11	-	

Table 4. Effect of different threshing methods on germination (%)

S. No.	Threshing methods	Crop	Germination (%)	References
1.	Barrel	Brown rice	79.38	(54)
2.	Thresher cleaner ASI		89.47	

Table 5. Effect of harvesting methods on germination (%) of rice varieties

S. No.	Harvesting and threshing method	Variety	Germination (%)	Vigour index	References
1.	Manual harvesting and manual threshing	CO51	96	3251	(56)
		CR1009 Sub 1	94	3519	
		Improved White Ponni	97	3317	
2.	Manual harvesting and mechanical threshing	CO51	93	2965	
		CR1009 Sub 1	90	3121	
		Improved White Ponni	91	2967	
3.	Combine harvesting	CO51	95	3057	
		CR1009 Sub 1	91	3255	
		Improved White Ponni	94	3087	

The germination of three cultivars, Nerica L 41, Jasmine 45 and Sikamo, utilizing a variety of threshing methods including box, barrel and machine before and after four months of storage. The results revealed that Sikamo threshed using a machine had the highest germination rate (88.83 %), whereas Sikamo threshed using a box had the lowest germination (62.67 %). While Jasmine-85 threshed by machine had the highest percent germination (89.00 %), Sikamo threshed by machine had the lowest germination (75.00 %) occurred after storage. There were no significant variations in storage methods as shown in Table 6, 7 (62).

The impact of combine harvesting, manual harvesting and threshing on two rice varieties namely ADT 36 and BPT 5204. Following the harvest, the seeds undergone with drying and processing before being stored in gunny bags at ambient temperature within a seed godown for a duration of 12 months. The study results revealed that the seeds harvested by the combine harvester maintained an optimal germination rate reaching 83 % for ADT 36 and 82 % for BPT 5204 even after 12 months of storage (Table 8, 9). Their recommendation emphasized that harvesting these rice varieties at 20 % moisture content using a combine harvester to meet the minimum seed certification standard of 80 %, sustaining quality for up to 9 months of storage (63).

The impact of various harvesting and threshing techniques on the storability of rice varieties, including CR1009 Sub 1, Improved White Ponni and CO 51, were examined, included manual harvesting and manual threshing, manual harvesting and mechanical threshing using an axial flow thresher and combine harvesting with pneumatic wheel and additionally, the seeds were treated with a water-soluble polymer at a ratio of 4 ml per 12 ml of water kg^{-1} of seeds and compared with untreated control seeds, along with storage conditions involved under ambient temperature in both super grain and gunny bags which results showed that manual harvesting and manual threshing resulted in the highest germination rates, followed by combine harvesting, with the lowest germination rates observed in manual harvesting and mechanical threshing. This decline in germination rates attributed to the aging effect on enzymes crucial for converting reserve food in the embryo into a usable form for seedling production. Furthermore, super grain bags were found to be more effective containers for maintaining seed quality across various seedling characteristics. Seeds coated with the water-soluble polymer exhibited the highest germination percentage, dry matter production and seedling vigour, while the control group showed the lowest germination rates, possibly due to mitochondrial membrane degradation, leading to a reduction in energy supply required for germination. These findings were consistent with previous studies conducted on rice (64). The study demonstrated that different rice varieties subjected to various harvesting and threshing methods, along with coating with a 4 mL + 12 mL of water kg^{-1} of seed and packed in super grain bag-maintained seed quality above minimum seed certification standards up to twelve months (25).

Harvesting methods like manual harvesting (MH) and combine harvesting (CH) and their effects on the storage potential of rice seeds were examined with four varieties such as NDR 97, NDR 359, BPT 5204 and Swarna Sub 1, by evaluating germination and field emergence over a six-months storage period. Seeds harvested manually which resulted in standard germination even after twelve days of harvesting, while seeds harvested using a combine harvester showed normal germination only a week after physiological maturity, in cv. NDR 97 in Table 10-13. Field emergence was significantly

Table 6. Effect of different threshing methods on fresh seed germination (%)

S. No.	Variety	Seed germination (%)			
		Threshing Methods			Mean
		Box	Barrel	Machine	
1.	Nerica-L41	81.67	81.67	74.00	79.11
2.	Jasmine -85	82.00	78.33	79.00	79.78
3.	Sikamo	62.67	83.33	88.33	78.11
	Mean	75.44	81.11	80.44	

LSD (0.01): Variety = 6.308; Threshing Method = 6.308; Variety x Threshing Method = 10.925.

Table 7. Effect of different threshing methods on stored seed germination (%)

S. No.	Variety	Seed germination (%)			
		Threshing Method			Mean
		Box	Barrel	Machine	
1.	Nerica-L41	86.08	85.00	84.58	85.22
2.	Jasmine -85	78.00	80.00	89.00	82.33
3.	Sikamo	88.00	84.67	75.00	82.56
	Mean	84.03	83.22	82.86	

LSD (0.01): Variety = 5.341; Threshing Method = 5.341; Variety x Threshing Method = 9.251.

Table 8. Effect of harvesting methods on germination (%) of ADT 36

Method of harvest	Seed germination (%) Storage period (months)				
	Fresh	3	6	9	12
Manual	94.52	93.41	90.12	87.51	85.21
Combine	94.32	92.28	89.52	86.23	83.28

Table 9. Effect of harvesting methods on germination (%) of BPT 204

Method of harvest	Seed germination % Storage period (months)				
	Fresh	3	6	9	12
Manual	91.67	89.31	86.67	86.00	83.51
Combine	91.33	87.44	84.62	83.60	82.00

Table 10. Seed germination and field emergence over six months of storage in rice cv. NDR 97

Storage(Month)	Days after 50 % anthesis									
	21		24		27		30		33	
	MH	CH	MH	CH	MH	CH	MH	CH	MH	CH
	Germination (%)									
1	96	85	95	88	90	86	88	85	85	81
2	95	84	94	86	89	85	86	84	85	79
3	95	84	93	85	88	83	85	83	84	78
4	94	84	92	84	87	83	84	82	82	77
5	93	83	92	83	87	82	82	81	81	76
6	93	83	91	82	86	82	80	80	80	76
C.D. (5 %)	0.72	0.76	1.05	1.23	1.12	1.19	1.18	1.22	1.24	1.32
	Field emergence (%)									
1	92	79	93	81	89	79	83	77	80	75
2	90	78	92	80	87	77	81	76	78	73
3	90	78	91	79	86	76	79	75	77	72
4	89	77	91	78	85	76	79	75	77	71
5	89	76	90	78	85	75	78	74	76	71
6	88	75	88	77	84	75	77	72	75	70
C.D. (5 %)	1.23	1.31	1.25	1.29	1.25	1.34	1.32	1.38	1.36	1.42

(MH= Manual Harvest, CH= Combine Harvest)

Table 11. Seed germination and field emergence over six months of storage in rice cv. NDR 359

Storage(Month)	Days after 50 % anthesis									
	28		31		34		37		40	
	MH	CH	MH	CH	MH	CH	MH	CH	MH	CH
	Germination (%)									
1	84	78	87	79	85	85	82	82	82	80
2	90	78	95	80	94	90	91	85	90	84
3	89	77	93	80	90	89	88	85	88	83
4	88	77	91	79	85	88	84	84	84	80
5	85	76	89	79	85	87	82	84	80	78
6	84	76	87	78	85	87	82	82	82	77
C.D. (5 %)	1.32	0.63	1.46	0.57	2.53	1.73	2.64	1.09	2.72	2.16
	Field emergence (%)									
1	80	70	85	72	81	75	79	73	73	71
2	87	70	90	75	88	77	84	76	78	74
3	86	69	89	75	85	77	83	76	78	72
4	85	69	88	72	84	76	83	75	76	72
5	84	68	86	72	84	76	82	75	75	71
6	83	68	85	71	82	74	80	73	75	70
C.D. (5 %)	1.53	0.76	1.61	1.72	2.66	1.82	1.87	1.17	1.94	1.23

(MH= Manual Harvest, CH= Combine Harvest)

Table 12. Seed germination and field emergence over six months of storage in rice cv. BPT 5204

Storage(Month)	Days after 50 % anthesis									
	35		38		41		44		47	
	MH	CH	MH	CH	MH	CH	MH	CH	MH	CH
Germination (%)										
1	86	80	89	83	87	84	83	81	82	80
2	92	82	93	86	90	86	88	82	87	85
3	92	82	92	85	89	85	86	82	85	83
4	88	81	89	84	88	85	83	81	80	79
5	86	81	89	83	87	83	83	81	82	78
6	84	79	86	82	86	83	82	80	79	75
C.D. (5 %)	2.45	1.05	1.96	1.21	1.32	1.14	2.12	0.63	2.23	2.52
Field emergence (%)										
1	81	72	84	75	82	76	77	75	74	71
2	89	75	90	79	86	78	80	74	78	72
3	88	75	90	79	85	77	80	74	77	72
4	83	74	88	78	85	77	79	73	77	70
5	82	74	85	78	84	76	79	73	76	70
6	82	72	84	77	81	76	78	73	76	69
C.D. (5 %)	2.61	1.24	2.05	0.74	1.17	0.78	0.74	0.76	0.43	0.51

(MH= Manual Harvest, CH= Combine Harvest)

Table 13. Seed germination and field emergence over six months of storage in rice cv. Swarna Sub 1

Storage(Month)	Days after 50 % anthesis									
	38		41		44		47		50	
	MH	CH	MH	CH	MH	CH	MH	CH	MH	CH
Germination (%)										
1	85	80	89	82	86	82	85	80	81	80
2	87	82	95	85	88	86	87	82	85	82
3	86	82	94	84	86	86	84	82	82	80
4	85	81	91	83	86	84	82	81	80	78
5	85	80	88	82	85	85	85	81	81	76
6	82	79	88	81	84	82	82	80	78	75
C.D. (5 %)	1.52	0.67	1.71	0.94	0.87	0.73	0.84	0.42	2.05	2.36
Field emergence (%)										
1	83	72	86	75	84	76	77	73	73	71
2	85	75	92	79	86	80	80	78	77	74
3	84	75	91	78	85	80	80	78	77	73
4	83	74	89	77	83	79	79	76	76	72
5	82	74	86	77	82	78	79	75	76	71
6	81	72	85	76	80	77	78	74	75	70
C.D. (5 %)	0.85	0.87	1.56	0.61	1.35	0.75	0.42	0.86	0.48	0.73

(MH= Manual Harvest, CH= Combine Harvest)

affected by both harvesting methods, with combine harvesting had more drastic impact, especially during storage. Seeds exposed to combine harvesting cause serious degenerative changes in metabolic activities. In cv. NDR 97, field emergence was notably higher when harvesting occurred three days after physiological maturity. Similar trends in germination and field emergence were observed in the other three varieties studied (NDR 359, BPT 5204 and Swarna Sub 1). However, there were differences in the case of combine harvesting, where field emergence was comparatively higher when harvesting was conducted around six days after physiological maturity. This difference may be attributed to the need for seeds to possess good health and natural robustness for rapid and complete germination, particularly to withstand the pressure employed during combine harvesting.

Post-harvest losses in food crops occurring during harvesting, threshing, drying, processing, storage and transportation etc. Cereal grains, a staple food source in many developing nations, experience significant post-harvest losses, with storage inefficiencies causing upto 50-60 % losses, which can be reduced to 1-2 % through storage methods (18). In Bangladesh, the use of hermetic storage bags proved more effective than traditional methods, maintaining 97 % germination with just 1 % damage, whereas traditional storage resulted in 95 % germination with 6 % damaged grains (66). The harvesting losses can occur through various ways such as harvesting, pre and post-harvest drying, threshing transport and storage (Table 14).

Table 14. Post-harvest losses in rice

S.No.	Aspects	Description strategy		References
		Cause	Reduction in Post harvest loss	
1	Pre-harvest drying	Harvesting before maturity entails the risk of loss through mold development leading to the decay of seeds	Maintain the moisture levels stay below the threshold level	
2	Harvesting	Seed crops damaged	Harvest the seed crop at the proper (Physiological maturity) maturity stage	
3	Threshing	Loss due to poor technique, susceptible to micro-organisms	Proper harvesting and threshing methods	
4	Post-harvest drying	Grain drying time depends on weather conditions and exposure to animals and pests can cause losses. Over-drying makes grains brittle, leading to breakage, insect damage and reduced market value.	•Wet grain should be dries preferably with in 24 hrs after harvest to avoid heat accumulation. •Fast and excessive drying should be avoided. •The threshed rice seed should be spread about 5 cm thick and dried with frequent mixing and tempering, preferably under less intense sunlight.	(8,67- 69)
5	Storage	Seed deterioration, insects, pests and diseases attacks, spillage contamination	Stored under suitable hermetic storage bags	
6	Transport	Prevent detached grains from spilling on the road before reaching the storage or threshing site or marketing place	Selection of suitable containers for commercial scale marketing	

Conclusion

Post-harvest losses and harvesting time are important factors in determining the quantity and quality of crop production. In numerous developing countries, low productivity is primarily attributed to limited adoption of modern technologies, inadequate management of recurring crop losses due to natural calamities and labour shortages. These losses are frequently associated with improper storage methods, degradation caused by insect pests and rodents and abiotic factors. Consequently, there is a necessity to develop cost effective methods for storing cereals and maintaining their viability, thereby mitigating the risk of insect infestation. To address the challenges associated with traditional manual rice harvesting and the yield reduction resulting from delayed harvesting, it is feasible to implement the combine harvesting method. This approach facilitates more efficient and timely harvesting, thereby reducing the likelihood of post-harvest losses and yield loss. Furthermore, the utilization of hermetic storage containers in conjunction with natural fumigants and insecticides can assist in deterring insect pests from stored seeds. By employing these techniques, it is possible to mitigate post-harvest losses and meet the increasing global demand for cereals, as well as to create new employment opportunities in technology enhancement and maintenance. The efficiency of combine harvesters becomes especially evident when harvesting extensive areas of crops, leading to improved yields and ultimately providing financial benefits to farmers.

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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