Quantitative and Qualitative Grain Losses of Wheat, Rice and Maize among Varieties during Mechanical Harvest

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Abstract Crop varieties highly affected the mechanical harvest outcomes both in quantity (grain losses) and quality (integrity of kernels) under 2025 weather conditions revealed by Funan experiments. The differential values of grain loss rates among quartile varieties' groups were averagely 34.95% for wheat, 24.16% for rice and 45.09% for maize. The differential values of the rates of broken kernels among quartile groups were on average 25.31% for wheat and 27.32% for maize. There was a negative correlation among grain moisture content (x) and grain losses (y) in mechanical harvesting, as $y = -0.0427x + 1.03$ for wheat, $y = -0.0766x + 2.6437$ for rice and $y = -0.1562x + 6.9908$ for maize. Both over-dehydrated and over-saturated kernels were more likely to be mechanically damaged (y as the % of broken kernels) by combiners as $y = -0.2721x + 4.273$ (wheat), $y = 1.4637x - 32.153$ (maize). It was suggested that in mechanical harvest, the grain moisture contents of wheat, rice and maize should be decreased to 13% – 18%, 25% – 28% and 22% – 28%, respectively, to decrease the grain losses and damages. It is recommended that in the crop variety registration procedure, some relevant information on mechanical harvest should be provided, more efforts should be given to the training of professional operators, and a modern 'AI for machine' system should be established in China.

Key words *Triticum aestivum* L.; *Oryza sativa* L.; *Zea mays* L.; Mechanical harvest; Genotypic difference; Agricultural modernization; AI for machine

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Grain losses during harvest are widespread in many countries for various reasons, leading to significant social, economic, and environmental impacts[1-2]. Reducing grain harvest losses is sometimes more important and cost-effective than simply focusing on increasing crop yield potentials[3]. Taking China as an example, grain losses during harvest for cereals were equivalent to 3.98% of the potential yield (2.95% for paddy rice, 3.00% for wheat and 5.20% for maize)[4]. Consequently, China has intensified the building of a nationwide food-loss-reduction system which covers the enhanced harvesting efficiency. Several operation standards for mechanical harvest yield loss control have been established, such as NY/T 498-2013, JB/T 5117-2017 and GB/T 21962-2020. According to these standards, grain losses in mechanical harvest for wheat, rice and maize are stipulated to be 1.2%, 2.8% and 4.0% as their upper limits. Following such efforts, mechanical harvest loss rates for wheat, rice and maize in 2024 dropped to 0.93%, 1.76% and 2.06%, respectively, highlighting 1% to 2% of loss-decrease compared with those in 2021 (official data).

There are various factors contributing to grain losses in mechanical harvest including the parameters of a combine-harvester *per se*[5-8], *status quo* of the crop to be harvested[9-12], weather conditions, performance of the operators[13], and even some social and economic considerations[14].

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Besides the above-mentioned quantitative yield losses, mechanical harvest also has its impacts on grain qualities. The mechanical operation can damage the kernels and cause incipient or hidden cracks which are the entry points for microorganisms and for grain breakage during drying and subsequent handling and shipping. Therefore, it is stipulated by the Chinese government that the percentage of the damaged kernels, also known as unsound kernels, must follow some certain standards. According to the national standards GB 1351-2008, GB 1350-2009 and GB/T 17890-2008, the percentage of unsound kernels needs to be ≤ 8% (as 'Grade Three') for wheat, ≤ 4% for rice and ≤ 8% (as 'Grade Three') for maize.

Agricultural modernization, represented by the all-round application of machines in plowing, sowing and harvesting, is highly developed in China. Nowadays, the rate of mechanical operation over laborers is as high as 76.6% for the production of all crops (from official data). Therefore, it is of great significance to understand the outcomes of mechanical harvest, both quantitatively and qualitatively, in the purpose of giving farmers more specific and feasible guidance. However, the influences of crop varieties on grain losses in mechanical harvest with respect to grain quantity and quality have not been fully studied. In this study, quantitative grain losses and qualitative grain damages of wheat, rice and maize during mechanical harvesting operation were analyzed, aiming to help farmers choose varieties, select machinery, and determine optimal operating parameters.

Materials and Methods

Location

Field experiments were taken in 2025 at Tianji Town

(33°42′16″N, 115°38′55″ E), Funan County, Fuyang, Anhui Province. The farm is located in the Yangtze – Huai Plain following a winter wheat-summer maize (winter wheat-soybean or winter wheat-paddy rice) crop rotation system.

Materials

Commercialized winter wheat, paddy rice and common maize varieties, 20 for each crop, were adopted (Table 1). Wheat was sown on 9th November 2024 into plots of 336 m^2 for each variety and was mechanically harvested on 27th May 2025 (combiner type: ZoomLionTG120). Rice was sown on 12th June into plots of 300 m^2 for each variety and was harvested on 31st October 2025 (combiner type: WORLD PRO). Maize was sown on 24th June into plots of 660 m^2 for each variety and was seed-harvested on 11th October 2025 (combiner type: WORLD PRO). Field management, including fertilization, irrigation and pest control, was kept the same with the local farmers.

Table 1 Crop varieties used for the experiment

Crop	Varieties *
Winter wheat	Bainong5819, Fengdecun12, Fuhangmai1, Fumai19, Fumai20, Fumai22, Hengjinmai9, Hengjinmai18, Huaimai920, Jintianmai8, Lianhangmai2, Luomai49, Pumai117, Qingyebai, Quanmai229, Wannong156, Xinshiji999, Yannong999, Zhengmai18, Zhongkemai12
Paddy rice	Fuliangyoujingyv, Heyouwuxiang, Huiyou98, Jiuliangyou3576, Leyoujietian2023, 3Liangyou911, Lvhan639, Lvhangeng1, Lvliangyoy778, Nongliangyou999, Quanzaoyou1606, Quanzaoyou851, Shengliangyou245, Wanfengyou107, Wanfengyou2, Wanfengyou668, Wanzhigeng006, Yinliangyou6019, Yinliangyoujietian, Zhuliangyou27
Common maize	Dongdan1331, Dongdan1331D, Dongdan1971, Dongdan2109, Futian168-2, Guohe303, HongshuoV9, Kangnongyu8009, Lianfannuo88, Lianyu520, Nongyu128, Nongyu662, Quanke785, Quanyin1188, Quanyu129, TY166, TY168, Wanzhonglian258, Zhonglian508K, Zhonglianyu555

* A total of 60 commercialized wheat, rice and maize varieties were adopted in this study and seeds were purchased from Anhui Zhonglian Seed Ltd. Co., with only a few varieties were still under Provincial registration tests.

Measurements and assessments

During mechanical harvest, grain yield of crop varieties was measured on spot individually. Randomly collected kernel samples from the harvest were taken back to the laboratory and were thoroughly dried in an oven. Grain moisture content was determined by the amount of water loss from the fresh kernels. Dry kernel weight was then calculated accordingly.

$$\text{Grain moisture content } (\%) = [(W_{\text{fresh kernels}} - W_{\text{dried kernels}}) / W_{\text{fresh kernels}}] \times 100$$

The above-mentioned samples were also used to measure the 'percentage of broken kernels', based on the weight of broken kernels out of the total sample weight.

$$\%\text{ of broken kernels} = [W_{\text{broken kernels}} / (W_{\text{broken kernels}} + W_{\text{sound kernels}})] \times 100$$

After harvest, we randomly collected the grain left in the field within a 0.1 075 m^2 sampling area, taking 3 to 4 replicates for each variety. The measures of the lost kernel weight were transferred into 'the lost kernel weight per m^2', which were used to calculate the 'percentage of grain loss'.

$$\%\text{ of grain loss} = [W_{\text{lost grain}} / (W_{\text{lost grain}} + W_{\text{harvest grain}})] \times 100$$

Statistical analysis

According to the measures and calculations, parameters (1) % of broken kernels and (2) % of grain loss for each variety of a crop were determined. Crop varieties were then classified by quartile grouping method into four groups as A (25% of the varieties with the highest values), B, C and D (25% of the varieties with the lowest values). Comparisons were taken among those quartile groups to demonstrate the differences in mechanical harvest within the classified varieties. Correlation analysis was taken using Excel statistical analysis model to evaluate the relationship between grain moisture content and grain losses.

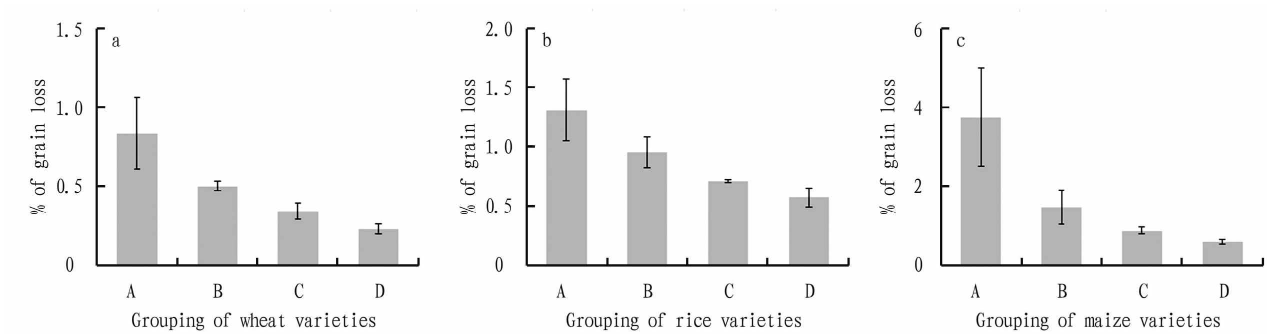
Results and Analysis

Weather conditions of the year 2025

The year 2025 experienced two weather constraints for agricultural production, namely spring drought and waterlogging summer throughout the Yangtze – Huai Plain region. In Funan County, for example, the accumulated precipitation from January to May was 140.1 mm. As it was 200.5 mm on average during 2017 to 2024, it showed 30.1% of decrease. The accumulated precipitation from June to October in 2025 was 614.0 mm. As averagely 461.3 mm in 2017 – 2024, it showed 33.1% of increase. Spring drought led to the premature senescence of wheat and the decreased yield performance at harvest. Waterlogging summer caused excessively saturated fields unsuitable for wheeled combine harvesters and only those equipped with tracks were applicable. It also led to postponed harvest and deteriorated yield performance due to various diseases infection.

Quantitative differences of grain losses among crop varieties

Results showed significant genotypic differences concerning mechanical harvest grain losses for all crops. In wheat, grain loss rates following combine harvester varied from 0.19% to 1.21% (with 0.48% on average) among twenty tested varieties. In rice, grain loss rates following combine harvester varied from 0.46% to 1.72% (averagely 0.90%) among the varieties. In maize, grain loss rates following combine harvester varied from 0.50% to 5.38% (with an average of 1.66%) among the varieties. Varieties were quartile-grouped into four groups as group A varieties were those gave the highest grain loss rates, and group D were those gave the lowest grain loss rates. For wheat varieties, the differential value among groups was 34.95% on average and those were 24.16% for rice and 45.09% for maize (Fig. 1).

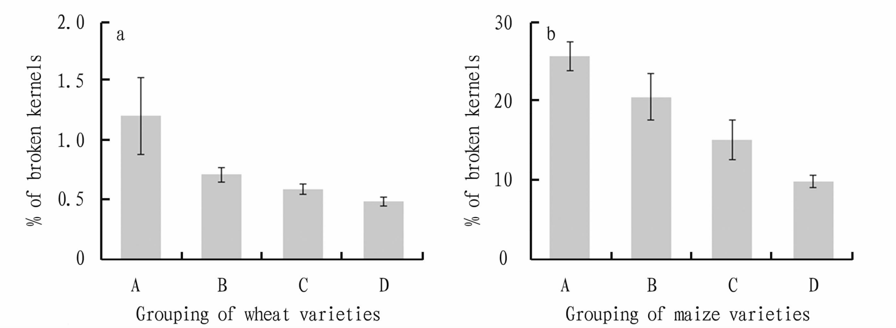


Twenty varieties were quartile grouped into four groups as A (the highest 25%), B, C and D (the lowest 25%). Bars were the standard deviation values. Experiments were taken in funan, anhui province, in 2025.

Fig. 1 Genotypic differences of grain losses in mechanical harvest in wheat (a), rice (b) and maize (c)

Qualitative differences of grain mechanically harvested among varieties

Significant genotypic differences concerning mechanically harvested grain qualities were also noticed. In wheat, the percentage of broken kernels, which was mechanically damaged by the combiner, varied from 0.44% to 1.16% (0.74% on average) among twenty varieties. In maize, the percentage of broken kernels due to mechanical harvesting varied from 8.92% to 28.93%, with an average of 17.76% among the varieties. Following comparison within four quartile groups of wheat varieties, there was a 25.31% difference among groups on average. For maize, the differential value among groups was averagely 27.32% (Fig. 2).

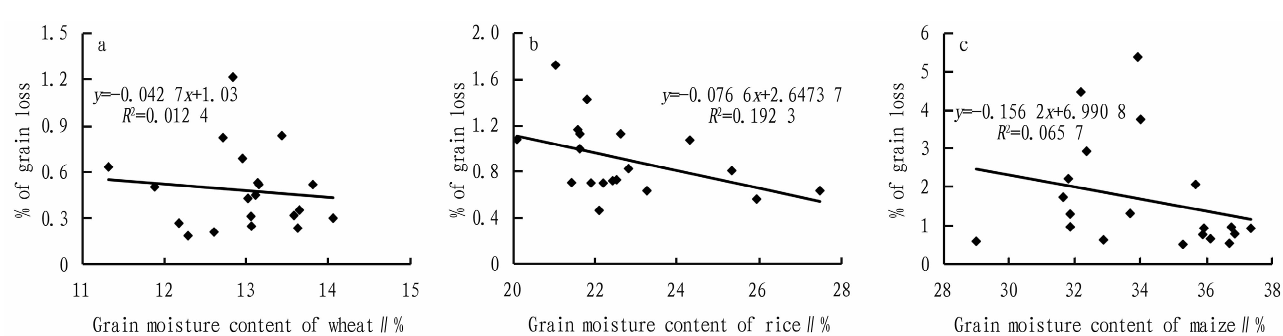


Twenty varieties were quartile grouped into four groups as A (the highest 25%), B, C and D (the lowest 25%). Bars were the standard deviation values. Experiments were taken in Funan, Anhui Province, in 2025.

Fig. 2 Genotypic differences of the percentage of broken kernels in mechanical harvest in wheat (a) and maize (b)

Impacts of grain moisture content on grain loss during mechanical harvest

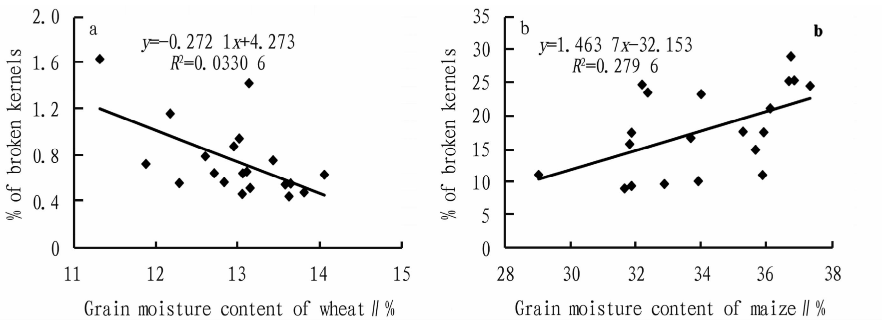
Results revealed that grain moisture content for harvested wheat was 11.32% – 14.06% among varieties, which were 20.10% – 27.50% for rice and 29.02% – 37.36% for maize, under the given circumstances (Fig. 3). Such results were attributed to the above-mentioned dry spring and wet summer. Grain quantitative losses during mechanical harvest were affected by the grain moisture contents. All three crops showed a negative correlation between grain moisture content and grain losses during mechanical harvesting, which highlighted the significance of determination of harvest timing. Relatively higher grain moisture content at harvest could lead to less winnowed kernels.



Experiments were taken in Funan, Anhui Province, in 2025.

Fig. 3 Relationship between grain moisture content and the rate of grain losses in mechanical harvest in wheat (a), rice (b) and maize (c)

Grain moisture content also affected the quality of the mechanically harvested crop kernels (Fig. 4). The rate of broken wheat kernels was negatively correlated with grain moisture content in the range of 11% – 14% (dry kernels). In contrast, the rate of broken maize kernels was positively correlated with grain moisture content in the range of 30% – 40% (wet kernels). This represented that both over-dehydrated (as in wheat) and over-saturated (as in maize) grain kernels were more easily to be mechanically damaged by combiners.



Experiments were taken in Funan, Anhui Province, in 2025.

Fig. 4 Relationship between grain moisture content and the percentage of broken kernels in mechanical harvesting wheat (a) and maize (b)

Taken both quantitative and qualitative grain losses/damages into consideration, it was thus recommended that in mechanical harvest of wheat, the grain moisture content should be dehydrated to 13% – 18%. For rice, it was recommended to be around 25% – 28%, and for maize to be about 22% – 28% to decrease the grain losses and damages during mechanical harvest.

Discussion

Diversity of crop varieties

China has made rapid progress in crop breeding during the recent years, which highly contributed to the crop yield increase. Taking Anhui Province as an example, within the latest 4 years (*i. e.* from 2022 to 2025), it officially registered and released around 200 wheat varieties, 424 rice varieties and 206 maize varieties (Table 2). Meanwhile, there were an even larger number of new varieties released by the neighboring provinces and even the nation-wide proved varieties. Therefore, there were far more than 100 varieties commercially available for each crop for farmers to choose from the market, which gave farmers a diverse option in variety selection.

Table 2 Number of wheat, rice and maize new varieties registered and released in Anhui Province during 2022 – 2025

Year	Wheat	Rice	Maize
2022	54	171	33
2023	56	102	42
2024	47	84	76
2025	43	67	55

Inadequate information in new variety guidance

According to the current registration standards, it is not obliged for breeders to provide relevant information on the effectiveness of mechanical harvest for crop varieties. Therefore, farmers have very limited information on harvest losses especially when they adopt some new varieties in their agricultural activity. In fact, plot-based trials in the regional test are under very different scenarios from the farm-scale production, which are mainly harvested by laborers or by small harvesters. In-field plant lodging, seed shattering, kernel size, hardness, uniformity in maturity, even diseases and pest sensitivities are all responsible for grain losses and are basically determined by relevant gene(s)[11,15–17]. Many of these parameters are easily to be overlooked in the registration procedure.

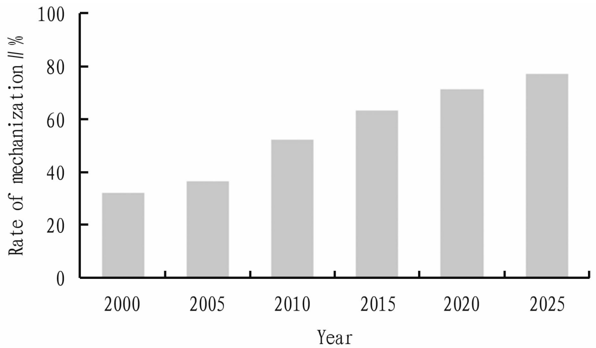
This study showed significant differences among crop varieties when they were harvested at the same time following the same mechanical operation. Such differences lied both in quantity and quality. Over 50% of the grain losses could be eliminated after a grower chose a 'good' variety instead of a 'bad' variety. It is therefore recommendable for breeders to provide some relevant information on mechanical harvest, so farmers can make better choice of variety selection according to the combiner's availability. This effort will be good for decreasing the yield losses during the harvest stage.

Emphasizing professional training of operators

Over 50% of Chinese farmers purchase harvest outsourcing services[2], as it is also the case in this study. The outsourcing service staff unavoidably differed in their operation skills, moral attitude towards the growers' profits and machine familiarity, all influencing the quality of mechanical operation. Results revealed that different combiner operators gave different harvest efficiencies (data not shown). Skilled operators would take into consideration of the crop situation and adjust to the suitable operation, such as harvest timing, the speed of the threshing rotor or cylinder, header height, and so on. As is widely known that after the optimal harvest timing in the season, maize harvest losses can increase 0.5% or more in yield reduction per week. If the combiner is operated at much higher throughputs, it causes greater losses. Under a certain and proper combiner loading, the combiner performs the best, while slow motion speed sacrifices the grain quality and fast motion speed escalates grain losses. It is thus also recommendable that larger efforts should be given to the training of the professional machine-operators to improve the quality of outsourcing service in China.

Modernizing mechanical equipment and support

Technology develops in an unprecedented speed nowadays. The rate of agricultural mechanization in plowing, planting and harvesting for some most important crops in China has soared from 32% in 2000 to 76.7% in 2025 (Fig. 5). Machine substituting for human labor has become an inevitable trend in modern agriculture globally.



Data were adopted from the official reports.

Fig. 5 Rate of agricultural mechanization in plowing, planting and harvesting for the most important crops in China during 2000 to 2025

The flourishing of artificial intelligence-based technology propels the agricultural mechanization even further. China is now making tremendous progress in vision-guidance, robotic systems, AI-based control units and equipment. Prospectively, a highly promoted production efficiency in agriculture driven by integrating mega data and 'AI for machine' is to be realized and in such a system, precise harvesting will be achieved for variable and delicate crops with the least grain yield losses and quality deterioration.

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