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IMPACT OF COMBINE HARVESTER SPEED ON WHEAT GRAIN LOSS: A FIELD STUDY IN MULTAN, PAKISTAN

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ABSTRACT

Wheat *(Triticum aestivum)* is the most important staple crop with a demand-based need to ensure food security but faces the challenges of timely harvesting at crop maturity. Harvesting operation of the wheat crop is one of the major activities during crop production and is important for food security and sustainability. The study's main purpose is to investigate the impact of vehicle speed on wheat grain losses during the harvesting operation. Varied speeds of the combine harvester were observed during the field tests and measured the grain losses by using a designed sampling method. The field observation recorded that the normal working speeds of the combine harvester were in a range of 7.54 km/hr to 11.77 km/hr during field tests with an average of 9.59 km/hr. The average grain losses were noted at 49.80 kg acre^{-1} with a percentage of 2.49% of total grain production in one acre. The highest grain losses were 69.11 kg acre^{-1} with a 3.46% percentage, identified at a vehicle speed of 11.77 km/hr, while the lowest at 7.54 km/hr that 35.35 kg acre^{-1} with a 1.76% percentage loss. Threshing losses significantly influenced the overall grain loss, which ranged from 1% to 1.8%, with specific grain damage from 0.36% to 1.07%, and shattering losses ranging from 0.4% to 0.65% due to variable vehicle speeds. The outcomes of the study found that field speed had a linear relationship with grain loss. Conclusively, the research findings provide guidelines to the machine operators and farmers should optimize the working speed to minimize grain loss during wheat harvesting.

Keywords: agricultural mechanization, harvesting efficiency**,** wheat, vehicle speed, optimization

INTRODUCTION

Wheat (*Triticum aestivum*) is one of the major cash crops and staple food for humans and the most valuable commodity (Nawi *et al.,* 2010). Pakistan is among the top 10 wheat-producing countries in the world (Food and Agriculture Organization, 2020). Wheat accounts for 60% of the average Pakistani's daily diet, with an average annual consumption of 125 kg capita^{-1} (Malik *et al.,* 2015). In the year 2017-18, the wheat cultivated area was 9 million hectares 0.5% higher than the previous year. During 2019-20, the production of wheat was raised by 3.2% than the previous year and recorded as 25.5 million tones, however, 5.1% less than the desired target. Forecasts showed that world wheat demand will increase by 35% to 56% by 2050 (Van Dijk *et al.,* 2021). Furthermore, the reduction in arable land due to housing societies, harvesting, and post-harvest losses, and inefficient energy use in agricultural production could create alarming conditions for food security (Ashraf *et al.,* 2020; Mahmood *et al.,* 2019). In this regard, enhancing productivity and reducing harvesting losses could help to sustain food security (Mairghany *et al.,* 2018).

Harvesting of the wheat crop is a very crucial issue at the time of crop maturity. The maturity date of wheat is generally in the middle of April and the start of May. Delay in the harvesting process affect the planting time, management strategies and hence yield of the next crop (Pattar *et al.,* 2001). The good production of the next crop depends on the sowing time, which highlights the importance of the timely and efficient harvesting process of field crop (Toro *et al.,* 2012). Due to the

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shortage of labor, combine harvesters are used in Pakistan to harvest the crop in an accurate time to reduce the delay time for the next crop and prevent crop loss. Combine harvesters are used for the harvesting of small grains, wheat, corn, and other cereal crops. The use of combine harvesters is the very successive solution to mitigate the shortage of labor for harvesting wheat crops in the world. (Mokhtor *et al.,* 2020). The combine harvesters make a huge contribution to agricultural productivity enhancement and time-saving. (Lenaerts *et al.,* 2012). Thus, mitigation of harvesting and postharvest wheat losses is an important element to ensure upcoming global food security. (Osunde and Orhevba, 2009). During the harvesting operation of wheat crops, the operational parameters like vehicle speed, weather conditions, crop moisture content (MC), and reel speed are of utmost importance. For the wheat harvesting process, the most critical factors in grain losses are in the form of shattering losses, threshing losses, and damage to grain (Shahar *et al.,* 2017). Following that to reduce the wheat grain losses, the operating variables i.e., vehicle speed and reel speed should be optimized. In this regard, soil moisture content also affects the vehicle speed in the field and working efficiency of the vehicle in the field.

Many studies were investigating the harvesting process of rice (Bawatharani *et al.,* 2016; Mairghany *et al.,* 2018; Mokhtor *et al.,* 2020; Pattar *et al.,* 2001; Shahar *et al.,* 2017; Suleiman *et al.,* 2019) and maize (Shaikh *et al.,* 2020; Tandzi and Mutengwa, 2019; Wang *et al.,* 2021; Zhang *et al.,* 2021) and other cereal crops, but a few studies were available on wheat harvesting (Asadullah *et al.,* 2014; Chaab *et al.,* 2020; He and Li, 2021; Pengfei *et al.,* 2018; Nawi *et al.,* 2010) that explores the effect of climatic conditions and harvesting schedule on wheat harvesting. In a study, the mean wheat yields are also demonstrated as a function of weather conditions (Ashraf *et al.,* 2021; Toro *et al.,* 2012). However, the harvesting speed of the machine plays an important role in grain losses. According to Adam and El Pebrian (2017), the speed of the combine harvester in the field greatly affects the farmers' satisfaction with mechanized wheat harvesting. In this regard, field efficiency increases with an increase in vehicle speed while enhancing grain losses. According to the American Society of Agriculture and Biological Engineering (ASABE, 2000). Standards the optimum speed of a combine harvester in rice harvesting should be between 3.0-and 6.5 Km/hr (Srivastava *et al.,* 2006). However, to the best of the author's knowledge, no information was found for wheat harvesting.

This study was conducted to present the impact assessment of the vehicle speed on wheat grain losses during the harvesting operation. This manuscript is an effort to investigate the influence of actual field speeds of the combine harvester as usually practiced by the operator in the field. Furthermore, the machine performance was examined based on threshing losses, shuttering losses, and the percentage of damaged grain during the harvesting process.

Data and methodology

Study area

The study area was selected near Sher Shah (30.1575° N, 71.5249°E) Multan (Pakistan), shown in Figure 1. There are harsh climatic conditions in the study area with average annual maximum and minimum temperatures of 46°C and 11°C, respectively. Multan lies in an arid to semi-arid region with an average annual rainfall of 167.3 mm. (Hussain *et al.,* 2024). During the monsoon season (i.e., July and August) maximum rainfall (45%) in the region occurs. Therefore, to meet the irrigation requirement canal water and groundwater pumping are required. Agriculture is the primary economic source for more than half of the population, indicating the main contribution to the total gross domestic product (GDP) of the country.

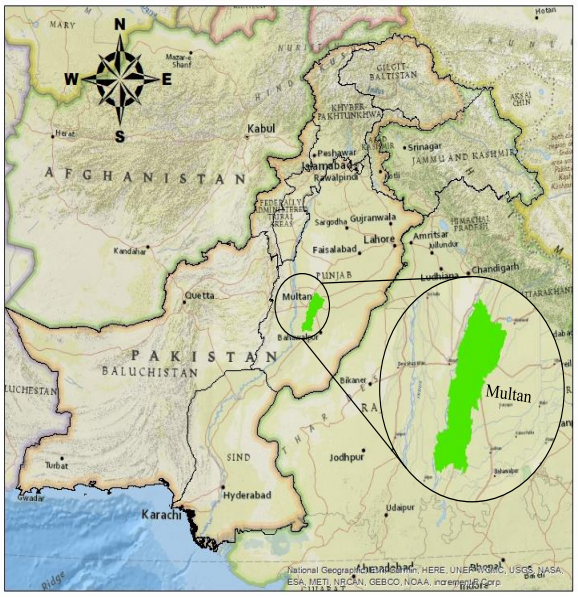

Figure 1. Map of the study area indicating the geographic location of Multan

METHODOLOGY

The actual field speeds of a combine harvester and respective losses were recorded by field experiments during wheat harvesting operations in the study area during the 2021 harvesting season. Three random fields in the study area were selected to experiment. The wheat variety ‘‘Faisalabad 2008” was cultivated in all the fields. The New Holland Clayson 8070 model of the combine harvester was used in this study.

The wheat age at harvesting time was 134 days and the mean temperature was 28°C. The moisture content (MC) in the grains was found in the range of 12% to 17%, while the average MC in soil was 14.5%. Furthermore, the plants were at an average tilt angle of 83 degrees with the ground. For the experimental treatments, one-acre field was divided into three sub-plots, and each plot had a 30m × 30m size as per the study (Mokhtor *et al.,* 2020). To collect the threshing and shattering sample, a 1 ft^2 metallic farm is place behind the machine to collect the seed. Plastic sheets were placed on both side edges of the reel mechanism of the combine harvester to collect the sample that fell out of the working width of the machine as shown in Figure 2. The grain damage was calculated by collecting the sample of 2000 wheat seed and segregating them based on their physical appearance. The various performance parameters (i.e., threshing losses, grain damage, and shuttering losses) were calculated to recode the overall grain losses. The time of travel for each 30m distance was recorded by using a measuring tape and a digital stopwatch, respectively. The average field speed of the vehicle was calculated using eq. (1)

$$\text{Average speed (s)} = \frac{\text{Total Distance (D)}}{\text{Total Time (T)}} \quad \text{Eq (1)}$$

where S is the field speed of the vehicle (Km/hr), D is the distance (m), and T is the time (hr). The grain breakages were determined using the eq. (2) provided by (Suleiman *et al.,* 2019).

$$\text{Damage Grain \%} = \frac{W_{dg}}{W_t} \quad \text{Eq (2)}$$

Where W_{dg} is the mass of damaged grain (g), W_t is the Total mass of the sample. In this study, specify that the effect of the total speed variation of combine harvester on grain losses as the total field harvesting losses. A sampling procedure was made in the sub-plots to measure the grain loss. Five quadrats of 1m × 1m size were randomly placed within each sub-plot. To collect the grain loss, the sampled areas were marked and cleaned from natural grain losses before the harvesting operation. Detail specifications of the combined harvester are shown in (Table 1).

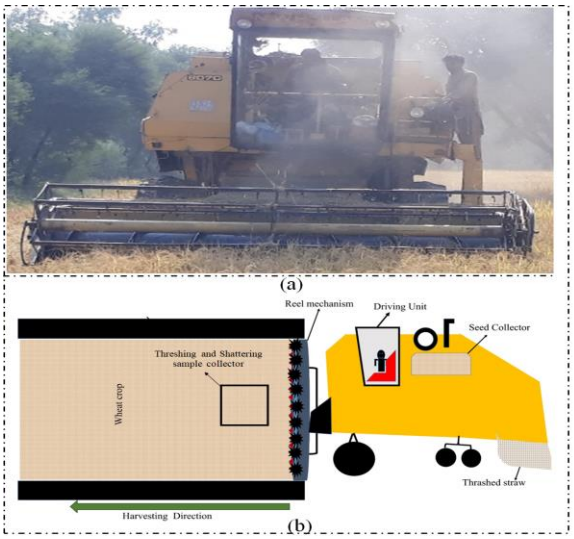

Figure 2. Pictorial representation of combine harvester (a) Field working (b) Schematic of sampling procedure

Table 1. Main specification of combine harvester specification

Feature of Machine	Specification
Make	NH
Model	Clayson 8070
Operational Power	140 hp
Driving Type	Wheel
Engine Type	2714ET
Fuel Tank capacity	300L
Engine Capacity	5945 cm^3
Header Width (Operational)	457 cm
Diameter of reel	107 cm
Maximum Speed	25 km /h
Threshing cylinder diameter	60 cm
Threshing cylinder width	130 cm

Note: New Holland (Manufacturers)

RESULTS AND DISCUSSION

The field experiments were performed to measure the overall grain losses of the combine harvester including threshing losses, grain damage, and shattering losses. Following the experiment, analyzed results were compared with the findings of various studies. Table 2 represents the field tests, operational speeds, total grain losses, and percentage of total grain loss under wheat field conditions. The random combine harvester speeds were in the ranged from 7.54 to 11.77 Km/hr, resulting in overall grain losses between 35.35 kg $acre^{-1}$ to 69.11 kg $acre^{-1}$ with percentage of 1.77% to 3.46% in one acre. The resulting values of per acre threshing losses, shuttering losses, and grain damage are presented in (Table 2)**.** During the field tests,

random vehicle speeds were between 7.54 km/hr to 11.77 km/hr which offered 19.8 to 34.7 kg acre^{-1} threshing losses, 8.35 to 13.11 kg acre^{-1} shattering losses, and 7.2 to 21.4 kg acre^{-1} loss with grain damages. The ASABE (American Society of Agricultural and Biological Engineers) recommends that grain losses during combine harvesting be kept to a minimum of 1%, with losses not exceeding 2-3% under particular field conditions. While the ASABE recommends these limits, some research suggests a range of 0.67% to 2.50% as being accepted depending on field conditions, particularly for crops such as rice and cereals (ASABE, 2000). These values indicate variables such as harvest speed, machine settings, and crop moisture, as higher speeds can considerably increase losses, especially when exceeding suggested levels. Despite this, overall repetitions of the field tests exhibit an increasing trend in grain loss as with the increase of field speeds. Furthermore, the incompatibility of the combine harvester reel and field speeds increases the amount of grain spread from the spikes.

Figure 3 is the graphical presentation of the combine harvester speed and the grain losses. The values depicted that the speed of the combine harvester is directly proportional to the grain losses. These findings were based on actual field conditions and experiments. The average vehicle speed was 9.59 km/hr during the harvesting operation of the wheat crop. The blue line in the graph shows the threshing losses. The calculated average of threshing losses was 26.44 kg acre^{-1}. During the high-speed operation, the wheat spikelet remains unthreshed which increases the percentage of threshing loss. The black line in the figure shows the shuttering losses. The average shuttering loss was about 10.83 kg acre^{-1}. The speed of the combine harvester reel and cutter bar movement significantly impacts the shattering of wheat seed from the spikelet, enhancing the changes of shattered losses that correlate with operational speed. It was noted that at the high speed, the maximum grain losses occurred. The red line represents the grain damage during the harvesting process. The average grain damage was 12.52 kg acre^{-1} which is less than grain damage in wheat crops as compared to the other countries. The grain damage during wheat harvesting is highly affected by the speed of the threshing cylinder, which changes with the operational speed of combine harvester.

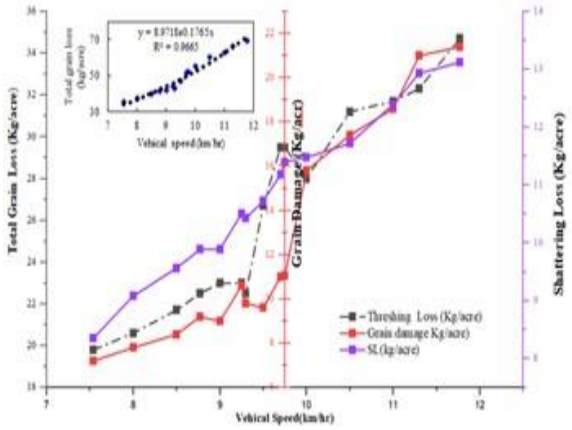

Figure 3. Graphical representation of vehicle speed relationship with total grain loss (Shattering loss, Threshing loss, and Grain damage)

Table 2. Experimental data of harvesting losses

Test No.	Vehicle speed (km/hr)	Threshing loss (kg acre^{-1})	Shattering loss (kg acre^{-1})	Grain damage (kg acre^{-1})	Total grain loss (kg acre^{-1})	% of Total grain loss
1	7.54	19.8	8.35	7.2	35.35	1.77
2	8	20.6	9.07	7.8	37.47	1.87
3	8.5	21.7	9.56	8.4	39.66	1.98
4	8.77	22.5	9.88	9.2	41.58	2.08
5	9	23	9.88	9	41.88	2.09
6	9.25	23	10.5	10.6	44.11	2.21
7	9.3	22.5	10.42	9.8	42.72	2.14
8	9.5	26.7	10.72	9.6	47.27	2.35
9	9.7	29.5	11.17	11	51.67	2.58
10	9.75	29.5	11.39	11.06	51.59	2.60
11	10	28	11.47	15.8	55.27	2.73
12	10.5	31.2	11.71	17.4	60.31	3.02
13	11	31.7	12.39	18.6	62.69	3.13
14	11.3	32.3	12.93	21	66.23	3.31
15	11.77	34.7	13.11	21.4	69.21	3.46
Average	9.59	26.44	10.83	12.52	49.80	2.49

In addition, the percentage of the grain losses is presented in Figure 4. The presented results were obtained from April and May during field experiments. Figure 4(a) presents the findings of the wise head-wise percentage loss shattering loss, threshing loss, and grain damage. The analysis of the results found that threshing and shattering losses show linear relationships with vehicle speed and grain losses, while grain damage follows an exponential relationship. Further, Figure 4 (b) bar height shows the percentage of total grain losses in one acre during randomized vehicle speed. The overall grain loss was significantly influenced by threshing losses, which range from about 1% to 1.73% due to varied vehicle speeds. Shattering losses specifically range from 0.41% to 0.65%, while grain damage ranges from 0.36% to 1.07%. The highest grain loss of 3.46% occurs at a vehicle speed of 11.77 km/hr, while the lowest loss of 1.76% is observed at a 7.5 km/hr vehicle speed.

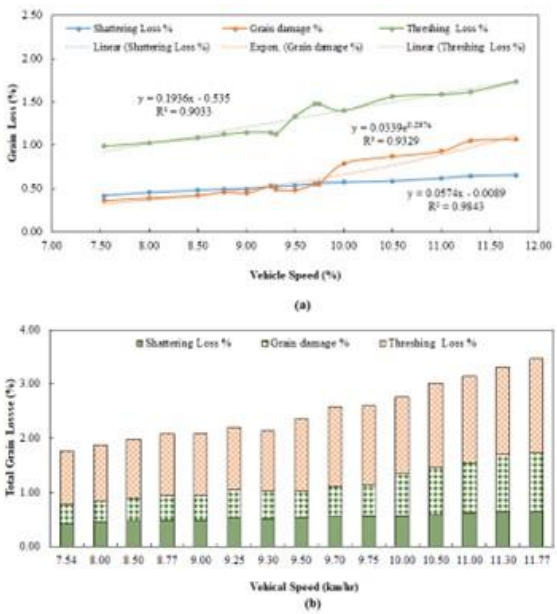

Figure 4. Graphical presentation of percentage grain losses (a) Head wise % loss (b) Total grain loss % per acre with the vehicle speed (Km/hr)

Figure 5 shows that total wheat grain loss increased with an increase in vehicle speed. According to the experimental results, the trend line of total wheat grain loss increased exponentially. as compared to vehicle speed with the exponential model fitting with maximum adjusted R^2 (i.e., 0.96055). Moreover, the empirical equation was developed to analyze the relationship between actual vehicle speed and total grain losses. In conclusion, the combine harvester speed should be smooth, managed, and streamlined which depends on the type of machinery being operated and the operator. In addition, the slope and leveling off the field also impact the vehicle speed of the combine harvester.

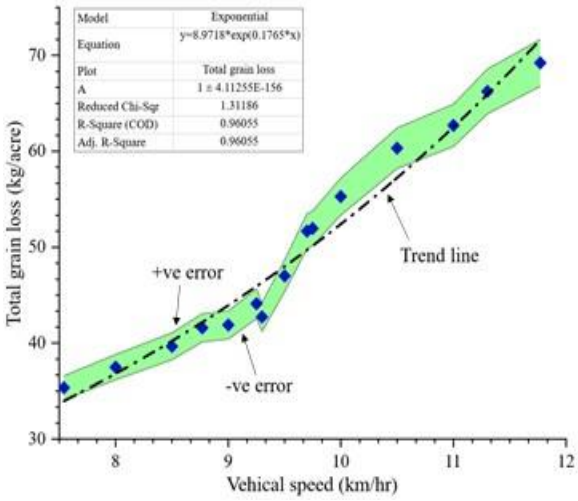

Figure 5. Graphical representation of vehicle speed relationship with total grain loss (kg $acre^{-1}$)

CONCLUSION

Wheat harvesting is a significant factor in getting the maximum yield after the application of other ingredients. The factor affecting wheat harvesting is presented in this study by investigating the impact of the actual field speed of the combined harvester on grain losses during wheat harvesting. The speed of the combine harvester was noted randomly changed by the operator in the field in ranged from 7.54 Km/hr to to11.77 Km/hr. Based on the key findings of the study, it was concluded that the field speed of the combine harvester had a significant effect on the grain losses during harvesting. The average of threshing losses, shattering losses, and grain damage was about 26.44 kg $acre^{-1}$, 10.83 kg $acre^{-1}$, and 12.52 kg $acre^{-1}$ at different speeds with an average of 9.59 km/hr during the field tests. The percentage of overall grain loss showed more contribution to threshing losses about 1% to 1.8% due to uncertain conditions of vehicle speed. While the percentage of shattering loss was in the range of 0.4% to 0.65%, and grain damage in 0.36% to 1.07%. The analysis shows a linear relationship for threshing and shattering losses, while exponential for grain damage with percentage of grain loss and vehicle speed. Furthermore, the

empirical equation of data revealed that the 74 kg acre^{-1} total grain loss at 11.77 Km/hr vehicle speed with prediction error. Conclusively, it was found that the total grain losses increase with the increasing vehicle speed and vice versa. Conclusively, future research should focus optimized the practiced vehicle speed during the harvesting operation to reduce grain losses with the relationship of reel index and threshing drum effect of the combine harvester.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR'S CONTRIBUTION

A. Khaliq: Intellectual/ contribution to paper in terms of Fieldwork, methodology, data collection, writing manuscript.
M. Z. Qasim: Intellectual/ contribution to paper in terms of Fieldwork, methodology, data collection, writing manuscript.
F. Ahmad: Intellectual/ contribution to paper in terms of Methodology, writing manuscript, critical review and editing.
H. S. Mahmood: Intellectual/ contribution to paper in terms of Critical review and editing.
Do Minh Cuong: Intellectual/ contribution to paper in terms of Critical review and editing.

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