INFLUENCE OF SELECTED HARVESTER PARAMETERS ON QUANTITATIVE AND QUALITATIVE LOSSES OF BREAD WHEAT

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ABSTRACT

Two field experiments were conducted on wheat crop in Al-Musayib township Babylon province during the agricultural season of 2011-2012 using Claas combine harvester. The first one was to determine the effect of forward speed of 2.4, 3.34, and 4.28 km h^{-1} and cutting height of 10, 20, and 30 cm on header, threshing cylinder, separation and cleaning, total harvester, and total losses and combine harvester efficiency. A randomized complete block design in a split plot arrangement with three replications was used. There is a trend of increase in total harvester losses accompanied by decrease in the efficiency as forward speed increases. Losses in all harvester units decreased whereas the efficiency increased as the cutting height increased. The forward speed of 2.4 km h^{-1} and cutting height of 30 cm gave the lower total harvester loss of 2.583 % and higher efficiency of 93.824 %. The second experiment was carried out to investigate the effect of forward speed of 2.4, 3.34, and 4.28 km h^{-1}, threshing cylinder rotational speed of 700, 800, and 900 rpm, and cylinder-concave clearance from the front and rear of 12-5 (c_1), 17-10 (c_2), and 22-15 (c_3) mm respectively on kernel damage and germination percentage of wheat grains. A split-split plot arrangement in a randomized complete block design with three replications was used. Results indicated an increase in kernel breakage and a decrease in grain germination due to decrease in forward speed, increase in cylinder rotational speed and decrease in clearance between cylinder and concave. The 4.28 km $h^{-1} \times c_3$ interaction gave the least kernel breakage of 5.396 % with the best grain germination of 96.301%. However, the 4.28 km h^{-1}×700 rpm interaction has lower kernel breakage of 5.562 % associated with higher grain germination of 96.913%. Whereas lower kernel breakage of 4.717% accompanied by greater germination of 96.859 % achieved by 700 rpm×c_3 interaction.

Keywords: Harvest loss, Header loss, Threshing cylinder loss, Separation and cleaning loss.

مجلة العلوم الزراعية العراقية – 44(2): 264-273، 2013 رمضان

تأثير عوامل منتخبة للحاصدة في الفقد الكمي والنوعي لحنطة الخبز

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المستخلص

نفذت تجربتين على محصول الحنطة في مدينة المسيب محافظة بابل خلال الموسم الزراعي 2011–2012 باستخدام الحاصدة المركبة Claas. اجريت التجربة الاولى لمعرفة تأثير السرع الامامية 2.4، 3.34، و 4.28 كم ساعة$^{-1}$ وارتفاعات القطع 10، 20، و30 سم في الفقد في وحدة القطع، اسطوانة الدراس، وحدة الفصل والتنظيف، فقد الحاصدة، الفقد الكلي، وكفاءة الحاصدة. استخدم تصميم القطاعات العشوائية الكاملة بترتيب القطع المنشقة بثلاث مكررات. هناك اتجاه لزيادة الفقد الكلي للحاصدة مصحوبا بانخفاض كفاءتها مع زيادة السرعة الامامية. انخفض الفقد في جميع وحدات الحاصدة بينما زادت كفاءتها بزيادة ارتفاع القطع. اعطت السرعة الامامية 2.4 كم ساعة$^{-1}$ وارتفاع القطع 30 سم اقل قيمة للفقد الكلي للحاصدة بلغ 2.583 % واعلى كفاءة بلغت 93.824 %. اجريت التجربة الثانية لدراسة تأثير السرع الامامية 2.4، 3.34، و4.28 كم ساعة$^{-1}$، سرع اسطوانة الدراس 700، 800، و900 دورة دقيقة$^{-1}$، والخلوص بين اسطوانة الدراس والمقعر من الامام والخلف 12–5 (c_1)، 17–10 (c_2)، و22–15 (c_3) ملم على التوالي في تلف الحبوب ونسبة الانبات لحبوب الحنطة. استخدم تصميم القطاعات العشوائية الكاملة بترتيب القطع المنشقة–المنشقة بثلاث مكررات. اظهرت النتائج زيادة تكسر الحبوب وانخفاض نسبة الانبات بانخفاض السرعة الامامية للحاصدة، زيادة سرعة دوران اسطوانة الدراس، وانخفاض الخلوص بين الاسطوانة والمقعر. اعطى التداخل بين 4.28 كم ساعة$^{-1}\times c_3$ اقل قيمة لتلف الحبوب 5.396% مع افضل نسبة انبات 96.301%. بينما اعطى التداخل 4.28 كم ساعة$^{-1}$×700 دورة دقيقة$^{-1}$ اقل مقدار لتلف الحبوب 5.562% مع اعلى نسبة انبات 96.913%. في حين اقل تلف للحبوب 4.717% مع اعلى نسبة انبات تم تحقيقهما للتداخل 700 دورة دقيقة$^{-1}\times c_3$.

كلمات مفتاحية: فقد الحصاد، فقد وحدة القطع، فقد وحدة الدراس، فقد وحدة الفصل والتنظيف.

Introduction

Bread wheat *Triticum aestivum* L. is considered one of the most economic crop participating in international income added to the local consumption in feeding and different aspects. Therefore, increasing the yield by means of up to date technology through the different agricultural processes, decreasing grain losses during harvesting. The study of Al-Jubouri (3) revealed that largest losses in the mechanical harvesting concentrated on the wrong performance in terms of regulation and the calibration of the operating units in the harvester, the farmer does not give importance to those variables and there were a set of interrelated factors that lead to reduce the efficiency of harvester performance involving the nature of the field, crop type, variety, maturity, lodging angle, and other factors. Chinsuwan et al. (10) stated that header losses of a combine harvester are a major problem in the harvesting process. Siebenmorgen et al. (26) revealed that there are two main factors that cause header losses, i.e. the crops themselves and the conditions of the machines including the harvester speed, and stem length or cutting height. Many investigations have been conducted on the losses in harvester units, of which the study of Al-Jubouri (2) who found that the loss percentage in combine header constitutes the largest loss percentage of total loss. The data presented by Al-Kazaz (4), Al-Tahhan et al. (5), Barać et al. (8), Chen et al. (9), Mohammed et al. (18), Ramadan (21), and Randal and Mark (23) indicated that forward speed plays an important role during harvest process in determining the proportion of harvest losses as it has negative impact in the process of harvest because losses proportionate with the speed of harvester due to its impact on the operating units and feeding rate. Stephen (28) found that grain losses in the cutting, threshing, separation, and cleaning units increase with increasing forward speed of the Massey Ferguson and Laverda combine harvesters. Separation of grain from materials other than grain with a least amount of loss and preservation of crop quality are some factors to which full attention must be paid in a good an efficient harvest. In recent years, a lot of works have been done on how to reduce grain losses during harvesting. There are however, other losses such as those arise from damage to quality and the breakage of grain, which are also needed to be considered. For example, the breakage of grain will adversely affect grain germination, storage capacity, grain processing operations and final price of the product. Arnold (6) and King and RiddoUs (14) indicate that cylinder speed is the primary influencing parameter while concave clearance, although of lesser significance, is an important factor as well. The study of Matter (17) indicated that machine loss was a function of, cylinder speed, cylinder concave clearance and feed rate as affected by forward speed. In the same direction Sweeting (29) stated that forward speed of the harvester plays a major role on increasing the quantity and quality loss in the grain and therefore workers should be aware of the circumstances of the use of ideal speed in the field. In an analysis and modeling experiment conducted by Kumar and Goss (15) as they used data obtained from 224 field experiments to present models for combine performance. Model presented for broken grains indicated significant correlation between cylinder speed and grain breakage. They found that an increase from 6 to 9 % in broken grains could be observed by an increase in cylinder peripheral speed from 20 to 25 m sec^{-1}, the results also supported by Khalid (13). The study of Prochazka et al. (20) revealed that increasing threshing cylinder speed could reduce the percentage of germination, so it must reach to the best speed combination included increase the percentage of germination, the researchers also found that the impact of cylinder rotational speed is much more than the impact of cylinder-concave clearance, especially in the percentage of germination. The study of Jakhro and Khan (12) showed that increasing forward speed decreased grain breakage due to increase feeding rate, the results also supported by Al-Jubouri (2) and ASAE (7). Many researcher determined the effect of cylinder rotational speed and cylinder concave clearance on losses in the threshing unit of which the study of Mansoori and Minaee (16). They found that an increase in cylinder-concave clearance results in less breakage of grain. In addition, increasing cylinder rotational speed from 750 to 950 rpm would double grain breakage, this results also in line with Sabir et al. (24). Thus, the objectives of this study were to measure quantitative loss of combine harvester units and harvester efficiency when harvesting wheat as affected by forward speed and cutting height of the header. In addition, to investigate the effects of harvester forward speed, cylinder rotational speed and clearance between cylinder and concave on grain breakage and germination. This should enable a prediction of the losses from the combine harvester and help farmers make appropriate decisions in their use, hence minimizing losses in the harvesting process according to the climatic and environmental conditions prevailing in our region.

Material and Methods

Two field experiments were carried out for threshing wheat Abu-Ghraib cultivar in Al-Musayib township Babylon province during the agricultural season of 2011-2012. The experiments were conducted using Claas combine harvester. Grain moisture content at harvesting was 12 - 14 %, determined by the oven-drying method ASAE (7). The first experiment was conducted to evaluate the effect of harvester forward speeds included 2.4, 3.34, and 4.28 km h^{-1} and cutting heights of the header included 10, 20, and 30 cm on header, threshing cylinder, separation and cleaning, total harvester, and total losses and combine harvester efficiency. A randomized complete block design under split plot arrangement with three replications was used. Forward speeds were allocated to main plots, whereas cutting heights were allocated to subplots. The harvest plot was 50 m long and its width was 4 m which was equal to harvester cutting width. Pegs were used to mark the beginning and the end of the treatment. A digital chronometer was used to measure the time required to pass the distance between pegs. Then, forward speed was adjusted along the 50 m length of the harvest plot to the desired speed. The following regulations was conducted, reel speed 24 rpm, threshing cylinder speed 800 rpm type of rasp bar, fan speed 650 rpm, upper and lower sieves openings 10 and 6 mm respectively, and cylinder-concave clearance on the front and back 17 and 10 mm respectively Randal and Mark (22). A wooden frame measuring 1 m^2 was used to collect data of pre-harvest grain losses. The wooden frame was randomly placed with ten replications at different locations of the selected field before harvesting wheat crop. The same area was harvested then threshed to determine the yield. After unit area conversion was made the total yield was 2321.732 kg ha^{-1}. Wheat grain losses on the header were determined by taking three samples (50×50 cm) of the scattered grains and spikes behind the cutter bar on where output material from the back of the harvester has not poured. Then grains and spikes in it were gathered, the spikes were threshed, all grains were weighed, and calculated as follows after making a unit area conversion:

$$HL = (B - A) \ldots\ldots\ldots\ldots\ldots (1)$$

Where:

HL = Header loss (kg ha^{-1}).

A = Weight of both collected grains and spikes due to natural loss (kg ha^{-1}).

B = Weight of both collected grains and spikes at the back of cutting bar (kg ha^{-1}).

Threshing cylinder loss was estimated from the grain inside the straw line behind the harvester, where the un threshed parts of the spikes were collected from the selected sample area. Losses on the separation and cleaning unit was estimated from grain loss under the straw line, after lifting the straw from the previous samples and collected the scattered grains then subtracting grain loss out of the straw line. The total yield was calculated from the following formula:

Total yield = Net yield in the harvester tank + Yield losses during harvest + Yield losses before harvest Then percentage of pre-harvest loss, percentages of the harvester losses, and total loss percentage was estimated. Harvester performance efficiency was calculated as following Srivastava et al. (27):

$$HE = \frac{NY}{NY + YL} \ldots\ldots\ldots\ldots\ldots (2)$$

Where:

HE = Harvester efficiency (%).

NY = Net yield in the harvester tank (kg).

YL = Yield losses during harvest (kg).

The second experiment was conducted using harvester forward speeds of 2, 2.94, and 3.88 km h^{-1}, threshing cylinder rotational speeds of 700, 800, and 900 rpm, and cylinder-concave clearances from the front and rear of 12-5 (c_1), 17-10 (c_2), and 22-15 (c_3) mm respectively. A split-split plot arrangement in a randomized complete block design with three replications was used. Main plots were forward speeds, subplots were rotational speeds, and sub-sub plots were cylinder-concave clearances. The harvest plot was the same dimensions of the first experiment. The cutting height of the header was 20 cm. The regulations of reel and fan speed, and sieves openings have been maintained as mentioned previously. Clearance between cylinder and concave as well as cylinder rotational speeds were adjusted prior to the start of the experiment. Cylinder rotational speed had been adjusted using an analog speedometer. After the combine had reached its predetermined steady forward speed, wheat samples were taken from storage tank in separated tagged sacks. One hundred gram of grain samples were taken from previously tagged sample sacks to determine the external damage inflicted upon the grain. The cracked, injured or split grains were carefully picked out to determine the percent of external damage Srivastava et al. (27).

$$GD = \frac{W_d}{W_s} \times 100 \,\ldots\ldots\ldots(3)$$

Where:
GD = Grain damage (%).
W_d = Weight of damaged grain(gm).
W_s = Weight of the sample (gm).

In order to determine the internal damage inflicted upon the grain, a germination test was conducted. Fifty grains were taken from each sacks and germinated in petri dishes. The percentage of germination was expressed on the basis of normal seedlings Agarwal (1).

$$\text{Germination }\% = \frac{\text{Number of normal, vigorous, and healthy seedlings}}{\text{Total number of seed}} \times 100 \ldots\ldots\ldots(4)$$

Data obtained from the field and laboratory experiments were analyzed by analysis of variance. Comparisons between treatment means were made by the protected least significant difference (LSD) at the 0.05 level Gomez and Gomez (11). Path analysis was used to examine causal relationships and understand comparative strengths of direct and indirect relationships among variables based on standardized (SD) coefficients Schumacker and Lomax (25) (Tab. 1). The statistical analysis was performed by using IBM SPSS Statistics 19 software.

Table 1. Path coefficients

		Estimate
Kernel Damage	Forward Speed	-0.426
Kernel Damage	Cylinder speed	0.639
Kernel Damage	Clearance	-0.564
Germination	Forward Speed	0.348
Germination	Cylinder speed	-0.594
Germination	Clearance	0.667

Results and discussion

First experiment

1- Forward speed

The results showed that forward speed had highly significant effect on header losses (Tab. 2). Increasing forward speed from 2.4 to 4.28 km h^{-1} increased header losses from 3.291 to 1.712 %. It is evident that more vibration occurred with increasing forward speed. Furthermore, the mismatch between the speed of the reel and the harvester which led to increased scattering of grain from the spikes. Similar results were reported by Stephen (28). The results also showed that header losses were superior to threshing cylinder, and separation and cleaning losses. For example, at forward speed of 4.28 km h^{-1}, the highest losses percentage was 3.291 % for header whereas it was 2.788 and 1.455 % for threshing cylinder and separation and cleaning units respectively. This results could be attributed to the large number of moving parts in the header such as the reel which its loss constitute a large proportion of the losses in the header. Decreasing reel rotational speed compared to the harvester forward speed lead to push dry spikes forward, breaking it, and fall some of them to the ground which increases the proportion of losses Ramadan (21). The results showed a highly significant increase in threshing cylinder loss with an increase in harvester speed (Table 2). The lower forward speed gave 0.872 % while it was 2.788 % for the higher forward speed. This was due to the excessive wheat plants in the threshing chamber, and thus throttling threshing cylinder with crop resulted in less impact force on the material and lack of sufficient opportunity to extract grain from spikes, consequently, wheat plants leave the device without complete threshing, which increased un threshed spikes, leading to high losses in this unit. This finding is also supported by Al-Jubouri (2), Randal and Mark (23), and Srivastava et al. (27). With respect to the separation and cleaning unit (Tab. 2), the losses increased highly significant with increasing forward speed. It increased by 51.247 % with increasing forward speed from 2.4 to 4.28 km h^{-1}. Increasing the forward speed led to high crop transfer rates over the straw walker. Thus the grain will pass over the straw walker without having a chance to go down through the holes because of the dense layers of straw and then increase the separation unit loss. This is in accordance with the results reported by Randal and Mark (23) and Stephen (28). Increasing forward speed also increased total harvester loss highly significant (Tab. 2). The highest value was 7.535 % accomplished by higher forward speed whereas it was 3.546 % for the lower forward speed. Increasing forward speed led to increase in the loss proportions of harvester units which collectively representing the total loss of the harvester. Highly significant increase was found in the effect of forward speed on total loss accompanied with highly significant decrease on harvester efficiency (Tab. 2). The speed of 4.28 km h^{-1} has highest rate of total loss of 9.375 % corresponding to lower efficiency of 85.229 %, whereas the speed of 2.4 km h^{-1} has lowest rate of total loss of 5.387 % corresponding to higher efficiency of 92.706 %. As forward speed increased all loss percentages of harvester units increased, as mentioned previously, which led to decrease harvester efficiency. The total loss percentage represents both total harvester units losses and pre-harvest loss. Similar finding was observed by Al-Jubouri (3), Al-Kazaz (4), and Barać et al. (8).

2- Cutting height

Influence of cutting height on header losses is shown in Tab. 3, which clarified that lowest cutting height of 10 cm caused highly significant increase in header loss of 3.237 % compared to the highest cutting height of 30 cm which recorded 1.860 %. This could be attributed to the large amount of crop harvested at the height of 10 cm due to the increased length of the plants stalks resulting plant jam in front of the cutter which led to fall of the spikes on the ground consequently increase losses. In addition to plants wrapping around the reel due to the increased length of plants stalks. Similarly, cutting height had highly significant effect on threshing cylinder loss (Tab. 3). It was 2.129 and 1.416 % for 10 and 30 cm cutting height respectively. The higher loss percentage for 10 cm cutting height could be attributed to throttling threshing cylinder with large amount of crop entering it. Because of increased stalks lengths which led to increase the amount of straw, that works as cushion, leading to decreasing threshing process and insufficient time to thresh spikes between threshing cylinder and concave, consequently increase the percentage of spikes containing grains (un threshed) and losses. This trend accords with Al-Jubouri (2). The data obtained clearly showed highly significant effect of cutting height on separation and cleaning losses (Tab. 3). The higher value was 1.353 % for 10 cm cutting height while it was 1.001 % for 30 cm cutting height. Increasing cutting height increased grain losses from straw walker due to overload. In addition to obstruct sieves by chaff causing grain flowing on the sieves and not getting out of the sieve's holes, then leaving the harvester by the fan air, thus increase losses. The effect of cutting height was also highly significant on total harvester loss, total loss, and harvester efficiency (Tab. 3). The cutting height of 10 cm gave the highest total harvester loss and total loss of 6.720 and 8.560 % respectively accompanied by the lowest efficiency of 87.913%. Whereas the cutting height of 30 cm gave the lowest total harvester loss and total loss of 4.278 and 6.119 % respectively accompanied by the highest efficiency of 90.410 %. The cutting height of 10 cm has the highest losses percentages of harvester units, and thus the high percentage of the total harvester and total losses which adversely affected the efficiency of the harvester.

3- Interaction effect of studied parameters on quantitative loss and harvester efficiency

Header loss:

The forward speed×cutting height interaction had a highly significant effect on the header loss. The data in Tab. 4 showed that forward speed of 4.28 km h^{-1} and cutting height of 10 cm gave the highest percentage of loss of 4.131 %, while forward speed of 2.4 km h^{-1} and cutting height of 30 cm gave the lowest percentage of loss of 1.151 %. The low percentage of loss was due to lack of noticeable knocking on spikes leads to increase grain scattering. In addition to directing the crop regularly to the transport unit. This is in accordance with the results reported by Mohammed and Al-Kazaz (18).

Threshing cylinder loss

It was found from the data presented in Table (4) that the effect of forward speed×cutting height on threshing cylinder loss was significant. The forward speed of 4.28 km h^{-1} and cutting height of 10 cm gave the highest percentage of threshing cylinder loss of 3.153 % whereas the lowest percentage of loss was 0.592 % for the 2.4 km h^{-1}×30 cm interaction. This was due to the regularity of crop feeding to the threshing unit which provide appropriate and continuous cushion of straw, thereby increasing the efficiency of threshing process. Similar finding was observed by Al-Jubouri (2).

Separation and Cleaning loss

It was clearly form the data presented in Table (4) the significant effect of forward speed×cutting height interaction. The 4.28 km h^{-1}×10 cm interaction gave the highest value of 1.684 % without differences from 4.28 km h^{-1}×20 cm interaction treatment, whereas the lowest values were 0.839 and 0.971 % for the 2.4 km h^{-1}×30 cm and 2.4 km h^{-1}×20 cm interactions respectively without differences between them. This was due to increase crop transmission speed over the straw walker, and thus less time required to separate the grain, and not to give enough chance for the grain to come down through straw layers (Wang et al. 31).

Total harvester loss, total loss, and harvester efficiency

The results also showed that there were highly significant effect in terms of the forward speed×cutting height interaction on total harvester loss, total loss, and significant effect on harvester efficiency Table (4). The highest loss percentages were 8.968 and 10.809 % for total harvester loss and total loss respectively for the 4.28 km h^{-1}×10 cm interaction treatment accompanied by the lowest efficiency of 84.187 %. Whereas, it was 2.583 and 4.424 % respectively for the 2.4 km h^{-1}×30 cm interaction treatment accompanied by the highest harvester efficiency of 93.824 %. This is contributed to the higher losses percentages on the cutting, threshing, and separation and cleaning units, consequently increased total harvester and total losses which reflected negatively on the efficiency.

Table 2. Effect of harvester forward speed on quantitative losses and harvester efficiency

Forward speed (km h^{-1})	Pre-harvest loss %	Header loss %	Threshing loss %	Separation & Cleaning loss %	Total Harvester Loss %	Total loss %	Harvester Efficiency %
2.4	1.840	1.712	0.872	0.962	3.546	5.387	92.706
3.34	1.840	2.488	1.673	1.134	5.296	7.136	89.465
4.28	1.840	3.291	2.788	1.455	7.535	9.375	85.229
LSD		0.2252	0.1347	0.1086	0.1307	0.1307	0.5187

Table 3. Effect of cutting height on quantitative losses and harvester efficiency

Cutting height (cm)	Pre-harvest loss %	Header loss %	Threshing loss %	Separation & Cleaning loss %	Total Harvester Loss %	Total loss %	Harvester Efficiency %
10	1.840	3.237	2.129	1.353	6.720	8.560	87.913
20	1.840	2.392	1.789	1.197	5.379	7.219	89.077
30	1.840	1.860	1.416	1.001	4.278	6.119	90.410
LSD		0.0610	0.1119	0.0890	0.1699	0.1699	0.3239

Table 4. The effect of interaction between forward speed and cutting height on quantitative loss and harvester efficiency

Forward speed km h^{-1}	Cutting height cm	Pre-harvest loss %	Header loss %	Threshing loss %	Separation & Cleaning loss %	Total Harvester Loss %	Total loss %	Combine Efficiency %
2.4	10	1.840	2.386	1.086	1.077	4.549	6.391	91.745
	20	1.840	1.597	0.938	0.971	3.506	5.347	92.548
	30	1.840	1.151	0.592	0.839	2.583	4.424	93.824
3.34	10	1.840	3.194	2.147	1.298	6.641	8.482	87.808
	20	1.840	2.406	1.581	1.076	5.064	6.904	89.561
	30	1.840	1.862	1.292	1.027	4.182	6.022	91.027
4.28	10	1.840	4.131	3.153	1.684	8.968	10.809	84.187
	20	1.840	3.172	2.851	1.543	7.566	9.407	85.121
	30	1.840	2.568	2.362	1.138	6.071	7.911	86.378
LSD			0.2206	0.1854	0.1482	0.2552	0.2552	0.6058

Second experiment

1- kernel damage %

The forward speed of the harvester had highly significant effect on decreasing the kernel damage loss (Table, 5). Kernel damage decreased from 8.950 to 6.667 % as forward speed increased from 2.4 to 4.28 km h^{-1}. This trend of decreasing kernel damage might be due to increasing feed rate which created cushioning effect resulting in less impact force on the individual kernels and hence less grain damage. The decrease in grain damage with an increase in feed rate has also been documented by Sabir et al. (24) and Vas and Harrison (30). Table (5) shows the effect of cylinder rotational speed on the kernel damage. The results indicated that the grain damage increased highly significant with an increase in cylinder speed for all clearances and forward speeds. The higher percentage of grain damage was 9.692 % at cylinder speed of 900 rpm, whereas the lowest was 6.268 % at cylinder speed of 700 rpm. This increase was due to higher impact levels imparted to the crop during threshing at higher cylinder speeds. The fact that increases in cylinder speed is accompanied by more grain mechanical damage is in accordance with results obtained by other research workers Mohtasebi et al. (19), Srivastava et al. (27), and Wang et al. (31). The highly significant effect of cylinder-concave clearance on kernel damage is shown in Table (5). The kernel damage showed a decreasing trend for all the forward speeds as the concave clearance was increased from c_1 to c_3. Considering the fact that threshing is accomplished through the two processes of impact and the grain being rubbed in between plant part layers, it becomes evident that decreasing the clearance between the cylinder and concave would add to the mechanical damage inflicted upon the grain. This is also confirmed by work down by Prochazka et al. (20), Stephen (28). Form the results of path analysis (Table, 1), increasing cylinder rotational speed was found to have the greatest effect on increasing kernel damage 0.639 SD, whereas increasing cylinder-concave clearance had higher effect on decreasing kernel damage -0.564 SD. The results also showed that there was significant effect on forward speed × cylinder speed interaction (Table, 5), Highly significant effect was observed either for forward speed × clearance (Table, 5) and cylinder speed × clearance (Table, 5) interactions. No significant difference was observed for forward speed × cylinder speed×clearance interaction (Table, 5).

2- Germination (%)

According to the results shown in Tab. 6, forward speed affected germination percentage highly significant. It increased from 92.186 to 94.476 % as increasing forward speed from 2.4 to 4.28 km h^{-1}. This results could be attributed to a reduced amount of impact force on the kernels due to large amount of crop material entering threshing cylinder that providing a cushion for the kernels hence less grain damage. This is in line with results reported by Jakhro and Khan (12).Table (6) also revealed that increasing cylinder rotational speed from 700 to 900 rpm resulted in highly significant lower germination percentage.

Table 5. The effect of forward speed, cylinder rotational speed, and cylinder-concave clearance on kernel damage (%)

Cylinder speed (rpm)	Clearance (mm)	Forward speed (km h^{-1}) 2.4	3.34	4.28	Cylinder speed× Clearance mean	Cylinder speed mean
700	c_1	9.316	7.283	6.656	7.752	6.268
	c_2	6.784	6.186	6.033	6.334	
	c_3	5.321	4.831	3.999	4.717	
Forward speed×cylinder speed mean		7.141	6.100	5.562		
800	c_1	10.53	8.348	6.802	8.560	7.228
	c_2	7.748	6.918	6.245	6.971	
	c_3	6.859	6.394	5.202	6.152	
Forward speed×cylinder speed mean		8.380	7.220	6.083		
900	c_1	13.66	11.25	10.56	11.82	9.692
	c_2	10.71	8.862	7.519	9.032	
	c_3	9.613	8.048	6.988	8.216	
Forward speed×cylinder speed mean		11.33	9.388	8.357		
Clearance (mm)					Clearance mean	
	c_1	11.16	8.962	8.007	9.379	
	c_2	8.416	7.322	6.599	7.446	
	c_3	7.264	6.424	5.396	6.362	
Forward speed mean		8.950	7.569	6.667		

LSD $_{\text{Forward speed}}$= 0.4074, LSD $_{\text{Cylinder speed}}$ = 0.3119, LSD $_{\text{Clearance}}$ = 0.2977, LSD $_{\text{Forward speed×Cylinder speed}}$ = 0.5320, LSD $_{\text{Forward speed×Clearance}}$ = 0.5236, LSD $_{\text{Cylinder speed×Clearance}}$ = 0.5073, LSD $_{\text{Forward speed×Cylinder speed×Clearance}}$ =Ns, Ns: Not significant.

Table 6. The effect of forward speed, cylinder rotational speed, and cylinder-concave clearance on germination (%)

Cylinder speed (rpm)	Clearance (mm)	Forward speed (km h^{-1}) 2.4	3.34	4.28	Cylinder speed× Clearance mean	Cylinder speed mean
700	c_1	91.304	93.236	95.736	93.425	95.199
	c_2	94.121	95.055	96.762	95.313	
	c_3	96.014	96.324	98.240	96.859	
Forward speed×cylinder speed mean		93.813	94.872	96.913		
800	c_1	90.024	92.296	92.704	91.675	93.565
	c_2	92.994	93.917	94.544	93.818	
	c_3	94.583	95.277	95.746	95.202	
Forward speed×cylinder speed mean		92.534	93.830	94.331		
900	c_1	86.372	88.353	88.783	87.836	91.295
	c_2	91.118	92.087	92.851	92.019	
	c_3	93.143	94.030	94.917	94.030	
Forward speed×cylinder speed mean		90.211	91.490	92.183		
Clearance (mm)					Clearance mean	
	c_1	89.233	91.295	92.407	90.979	
	c_2	92.744	93.687	94.719	93.717	
	c_3	94.580	95.210	96.301	95.364	
Forward speed mean		92.186	93.397	94.476		

LSD $_{\text{Forward speed}}$= 0.7842, LSD $_{\text{Cylinder speed}}$ = 0.4383, LSD $_{\text{Clearance}}$ = 0.3581, LSD $_{\text{Forward speed×Cylinder speed}}$ = 0.8728, LSD $_{\text{Forward speed×Clearance}}$ = 0.8223, LSD $_{\text{Cylinder speed×Clearance}}$ = 0.6466., LSD $_{\text{Forward speed×Cylinder speed×Clearance}}$ =Ns, Ns: Not significant.

This is also confirmed by work down by Jakhro and Khan (12) and Srivastava et al. (27).The analysis of variance showed that the cylinder-concave clearance highly These are attributed to high stripping and impacting forces applied to the grains, that tends to increase damaged and injured grains, which decreased germination percentage significant affected germination percentage (Table, 6). The germination percentage increased rapidly as the cylinder-concave clearance increased from c_1 to c_3. Increasing cylinder-concave clearance led to alleviate the impact of the threshing cylinder on the grain, which increased the percentage of germination. This result agrees with Mohtasebi et al. (19) and Stephen (28). The results of path analysis (Table, 1) showed that increasing cylinder-concave clearance had a bigger effect of 0.667 SD on increasing germination percentage, while increasing cylinder rotational speed resulting in higher decrease in germination percentage of -0.594 SD. These findings are consistent with Prochazka et al. (20).Concerning the effect of interaction, results obtained showed significant forward speed×cylinder speed (Table, 6), highly significant forward speed×clearance (Table, 6), and cylinder speed×clearance (Table, 6) interactions. No significant interaction existed between forward speed × cylinder speed × clearance. Generally, increasing forward speed, cylinder speed and decreasing cylinder-concave clearance decreased germination percentage considerably. Results of this study showed that forward speed and cutting height play important role on affecting quantitative loss and efficiency of the combine harvester. As the forward speed increased, the total harvester losses increased and the harvester efficiency decreased. Increasing cutting height decreases total harvester losses, while it increases harvester efficiency. Lower forward speed with higher cutting height seems to be more convenient to reduce total harvester losses and achieved higher efficiency. Furthermore, forward speed, cylinder rotational speed, and cylinder-concave clearance were a significant factors causing physical and physiological damages to wheat grains. With increasing forward speed and cylinder rotational speed kernel damage increased. However, increasing cylinder-concave clearance decreased kernel damage. The germination percentage was directly proportional to the forward speed and cylinder-concave clearance and inversely proportional to the cylinder speed. It is recommended that reducing forward speed and cylinder rotational speed with increasing cylinder-concave clearance to obtain minimum kernel damage and better germination.

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