**Evaluating and comparing the efficiency of rice combine harvesters in Iran**

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**Abstract**

Behind wheat, the largest cultivated area worldwide is devoted to rice. Rice as a strategic agricultural commodity has become considered to be of prime importance for supplying the dietary energy of more than half of the world’s population. Used rice combine harvesters with a variety of mechanisms probably function diversely. The current study aimed at evaluating different types of commonly used rice combine harvesters’ performances in Iran. The evaluation criteria include fuel consumption, theoretical field capacity, effective field capacity, quantitative and qualitative losses. The experiments were carried out in completely random conditions with three replications in paddy fields located in northern Iran, Mazandaran. The results revealed that the difference between the percentage of wastes, theoretical and effective field capacities and the amount of quantitative and qualitative losses of combine harvesters were statistically significant at the level of 1% probability. But, there was not a significant difference between the losses percentage. Although on the one hand, the head-feed combine harvester had the highest rate of field yield with 77.79%, it had the highest rate of grain loss with 2.24% (excluding natural shedding) compared to the whole-feed combine harvester, on the other hand. According to the obtained results, it is technically recommended to use the head-feed combine to harvest rice in the study area.

Keywords: Mechanized Rice Harvesting, Rice Combine, the head-feed combine, the whole-feed combine

1. **Introduction**

In Iran, most paddy fields (410,000 hectares or 40% of the total area under rice cultivation) are located in Mazandaran Province. Due to the increase in population and rice consumption, it is necessary to use mechanized rice harvesting methods rather than conventional ones. Since efficiency and performance of rice combine harvesters depend to a large extent on the conditions of land, crop, and region, combine harvesters should be tested in local conditions. If the localized efficiency is confirmed, users should be provided with the instructions for appropriate use and adjustment(Paulsen, Kalita et al. 2015).

Regarding the effect of field and crop conditions on field performance of combine harvesters, field capacity and efficiency might vary depending on the cultivation pattern and type of crop. Factors such as cultivation method, grain moisture percentage, field lodging percentage, crop yield, and field length can affect the field performance of combines so that the topographic conditions of the field and the higher manoeuvring power of the machine may accelerate the harvesting in the fields without beds and furrows compared to other cultivation patterns (Ghaseminezhad, Faramehr et al. 2018). Furthermore, the findings of the study demonstrated that the lower the moisture content of the crop and grain, the higher the total loss (Ghaseminezhad, Faramehr et al. 2018). according to the findings of another study, with decreasing of paddy grain moisture content from 22% to 19%, the total shattering rice grain decreased by 68%, and with increasing of grain moisture content from 17% to 19%, the total shattering decreased by 65% (Al Sharifi, Aljibouri et al. 2019). The findings of the research showed that the field speed of combine in harvesting rice in conditions of Malaysian paddy fields varies from 3.87 km/h to 6.11 km/h; While the best field speed was observed at 3.87 km/h, which resulted in only 0.67% of grain loss or 8.04 MYR/ha (1.96 USD/ha) profit loss. There was also a direct correlation between field speed and grain loss. Accordingly, the results can encourage the mechanization quality improvement in order to reduce the profit loss of rice farmers by minimizing grain loss in rice harvesting (Mokhtor, El Pebrian et al. 2020). Factors such as harvest time, crop moisture, humidity, topography, appropriate operation safety factor of combine mechanisms, and knowledge of the harvested crop characteristics are effective in reducing crop loss; and people involved in harvesting should have sufficient experience, and working knowledge of harvesting operations (Paulsen, Kalita et al. 2015). The operational performance can be a significant and decisive criterion in selecting a combine. Based on the findings of a study, to improve the performance of straw walker combine harvesters, the gap between the fan and the sieve could be adjusted, so that the fan blows air on the sieves constantly and prevents the grains from entering into the straw tank. Moreover, by minimizing the width of the cutting header, the losses of the cutting unit can be reduced (Lotfalian and Hosseinzadeh, 2018). designing and manufacturing agricultural machinery should be localized based on the anthropometric characteristics of real users to avoid making unnecessary demands on them (Ghaderi, Maleki et al. 2014). The results of another research on the assessment of field performance of head-feed and whole-crop combine harvesters in mechanized rice harvesting showed that the whole-crop and head-feed combine harvesters had the highest and lowest field capacity and efficiency, respectively. There was no significant difference between the performances of combine harvesters regarding the shattering rate. Additionally, at the level of 5% of probability, there was a (statistically) significant difference between experimental treatments in terms of loss percentage, theoretical and effective capacities and cost per hectare of land (Amini, Rohani et al. 2020). Findings of another research showed that self-propelled whole-crop paddy combine harvester (model 4LZ-2A) had the most optimal performance in paddy fields of Mazandaran. A capacity of 0.62 ha/hr, field efficiency of 75.8% with average field speed of 4.09 km/hr, and average grain loss of 4.8% were the results of the aforementioned model assessment. besides, proper adjustment was mentioned as one of the factors in reducing combine harvesters’ losses (Paulsen, Kalita et al. 2015). The efficiency and capacity of combine harvesters are defined proportionate to the size of paddy field, the type of machine, and the pattern of work; thereby, practical capacity and purchase price are the most important determinant factors in their operating costs. For long-term development, larger combines are more economical (Weng and Chen 2016). The research conducted by Belal et al (2017) showed that the performance of combine harvesters in paddy fields was affected by rice production performance. The expected percentage of bran differed significantly depending on the type of harvesters. Combine wear and tear could affect rice purity. Using simulation techniques such as CFD, they were able to simulate the airflow behaviour in the combine and suggest appropriate solutions to create a unified airflow. Also, the cleaning unit of rice harvesting combines could effectively affect the capacity of the machine. High grain sieve losses and high impurities in capacities above three kg/s for combines are conceivable. Improving work capacity and reducing rice operating costs require reviewing rice work and efficiency patterns (Weng and Chen 2016). It was found out that the average rate of wheat natural losses, combine losses, and totally natural and combine losses of wheat harvest in Qom province were 1.66%, 1.41%, and 3.07%, respectively; from which, 0.06 % of the losses was attributed to the end of the combine, and 1.35 % was attributed to the header of the combine (Amini, Rohani et al. 2020). In another study, rice grain sieve losses in rice combine harvesters were evaluated using a monitoring system, and field tests were conducted using an extended mathematical model based on laboratory test results, and the results showed that measurement errors were less than 3.83%. (Liang, Li et al. 2016)

Recently, Iranian farmers have been using various combine harvesters exported from South-eastern Asia without considering their technical and economic aspects. To the best of the current researcher’s knowledge, there is no research to compare the technical and functional issues of rice harvesters based on scientific and standard methods. The high price of such combine harvesters can clarify and justify the importance of the scientific and technical selection of the machine, because the operational performance of rice combine harvesters may vary depending on the local conditions of regions. In the current study, different rice harvesting methods with commonly used combine harvesters, operational capacity, and related parameters were evaluated. In this regard, 13 different models of paddy combine harvesters (head-feed and whole-feed types) were compared.

1. **Materials and methods**
	1. **Data of the test**

To achieve the aims of the study, 13 models of different types of frequently imported paddy combine harvesters to Iran as well as those manufactured in the country that are commonly used by Iranian farmers were chosen. The set of combine harvesters used in the current study included the ones imported from South Korea, China, Japan, and a domestically manufactured model. All 13 combine models were tested in an idle condition in paddy farms of Mazandaran province by the North Quality Promotion Company as a partner laboratory of the Iranian National Standard Organization and a testing institution consisting of university professors under the supervision of the Mechanization Development Centre of the Ministry of Agriculture Jihad. The machines were evaluated and tested according to the standards of ISO 8210, ISO 8210, ISO 1-6689, ISO 2-6689 in three laboratory, workshop, and applied (field) stages in Iran during the cropping years of 2017-18. Measurements included determining the amount of fuel consumption, advancing speed, theoretical and practical field capacities, field efficiency, wastes, and drops.

Table 1. technical specifications of combine harvesters

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| --- | --- | --- | --- | --- |
| Type | Model | Country of origin | Power of the engine (kW) | Cutting width (cm) |
| Head feed | 4LZ-2.0B | China | 60 | 220 |
| Head feed | 4LZ-2.5 | China | 55 | 205 |
| Head feed | 4LZ-3.0 | China | 73.5 | 220 |
| Head feed | 4LZ-5.0 | China | 73 | 225 |
| Head feed | 4LZ-4.0ZD | China | 54 | 200 |
| Head feed | 4LZ-4.6 | China | 73.5 | 210 |
| Head feed | 4LZ-4G1 | China | 65 | 215 |
| Head feed | 4LZ-4.0QB | China | 70 | 220 |
| Head feed | AU201-B | China | 63 | 200 |
| Whole feed | CX585G | South Korea | 63 | 170 |
| Head feed | DC-70G | Japan | 65 | 200 |
| Head feed | DELTA 2300 | Iran | 73.5 | 230 |
| Head feed | TH750C | China | 55 | 200 |

* 1. **Criteria of the test**

The tested combine harvesters were of the self-propelled type with independent engines that performed harvesting, threshing, and winnowing operations of the standing crops simultaneously. The main parts of these combines include propulsion unit, harvesting unit, crop transfer unit, threshing unit, cleaning unit (winnowing), tank, and grain transfer unit. All tests were performed for Tarom Hashemi rice in paddy fields of Mazandaran Province in 2017-2018 with 3 replications. The tests were performed at 10 am, and the soil moisture in all test conditions was 20-30%. Fourteen criteria were used to evaluate the performance of combines (Table 2).

Table 2. Criteria measured for comparing the performance of rice harvesting combine machines

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| --- | --- | --- | --- | --- | --- |
| Criterion | Symbol | Unit | Criterion | Symbol | Unit |
| Field efficiency | Fe | % | Total loss | HL | % |
| Field capacity | Ce | ha/hr | Unthreshed grains | UBc | % |
| Fuel consumption | F | Lit/ha | Purity of grains | Pg | % |
| Broken grains  | Bs | % | Unfilled or immature grains | EIs | % |
| Peeled grains | Bs | % | Weed seed | Ws | % |
| Processing losses | Pp | % | Straw  | S | % |
| Header losses | Pi | % | Cracked grains | Cs | % |
| Natural losses | Pn | % |  |  |  |

* + 1. **Fuel consumption**

In order to measure fuel consumption, first of all, the combine was placed on a perfectly flat surface, and then the inside of the tank was filled to a certain level with fuel. After harvesting a particular area within the field, refuelling was resumed. The amount of fuel consumed in the second stage of refuelling was indicative of the amount of fuel consumed at the functional level (Equation 1). Each experiment was performed in three replicates.

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| $$F=\frac{F\_{2}}{A}$$ | (1) |

Where *F* is fuel consumption (lit/ha), *F2* is refuelling rate (lit), and *A* is farm area harvested (m2).

Figure 1. Measurement of fuel on the farm

* + 1. **Field efficiency and effective field capacity**

Theoretical field capacity (*Ct*) is obtained based on the entire width of the machine without considering time wasted at a given advancing speed (Pirot 1999). The theoretical field capacity calculated through equation 2 represents the size of area covered by the machine without considering wasted times. . The effective field capacity obtained through equation 3 represents the actual operating time of machine with taking account wasted times, and accordingly it’s a function of the theoretical capacity and field efficiency. Besides, according to the equation 4, field efficiency is the ratio of actual field capacity to the theoretical field capacity.

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| $C\_{t}=S×W/10$  | (2) |
| $$C\_{e}=\frac{A}{T}$$ | (3) |
| $$F\_{e}=\frac{C\_{e}}{C\_{t}}×100$$ | (4) |

Where *S* is the advancing speed (km/h), *W* is the operational width (m), *Ct* is the theoretical capacity (ha/hr), *A* is the harvested area (ha), *T* is the specified time (hr), *Ce* is the effective field capacity (ha/hr), and *Fe* is field efficiency (%).

* + 1. **Losses**
			1. **Normal losses**

Although natural losses are irrelevant to the performance of combine harvesters, knowing the amount is necessary for measuring other kinds of losses (Figure 2). For this purpose, wooden frames of 1 square meter were placed in different points of the 1x1 tested plots. After separating the paddies inside and outside the frames, the pristine and undamaged paddies on the ground (inside the frames in front of the combine and before moving the combine) were collected and weighed. Natural drops can be measured in any area of the field, but to increase the accuracy of the measurement, the frames were placed in front of the combine so that other wastes could be examined in the same area after the operation.

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| $$P\_{n}= \frac{W\_{b}}{W\_{a}+W\_{b}}×100$$ | (5) |

Where, *Pn* is the natural grain losses (%), *Wa* is the weight of grains in standing plants that can be harvested with a combine (gr), *Wb* is the weight of grains that have fallen before the combine enters the field (gr).

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Figure 2. Natural drop measurement

* + - 1. **Combine header losses (collection loss)**

During its regular operation, the combine was stopped and steered back 4 meters in the same direction of advancing. In the space between the unharvested crop in front of the combine and the point where the straw walker has not yet reached (2 meters), a wooden frame of 1 square meter was placed and the grains on the ground were collected and weighed inside the wooden frame. For measuring the amount of shattering in this area, the number of drops was deducted before harvest.

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| $$P\_{i}= \frac{W\_{q}×10}{Y\_{t}×n×A\_{k}}×100-P\_{n}$$ | (6) |
| $$Y\_{t}= \frac{(W\_{a}+W\_{b})×10}{n×A\_{k}}$$ | (7) |

Where *Pi* is the grain losses on the cutting platform (%), *n* is the number of framing times (kg/Ha), *Wq* is the total weight of collected grains within the box (gr), Yt total grain produced per unit area, *Ak* is sampling frame area (m2).

Figure 3. Collection loss measurement

* + - 1. **Processing unit losses (blower, crusher, separator, straw walker)**

For this purpose, at first, in the middle parts of the plot (along the length), poles with a distance of 10 meters from each other were planted. As soon as the combine reached the first pole, the straw discharge and winnowing outputs were collected using pre-prepared tenets, and once the combine reached the next pole, it was stopped. This operation was performed separately for straw and winnowing outputs. After marking the samples with identification codes and transferring them to the laboratory, all undamaged grains were separated and weighed. The number of shattered grains resulting from a threshing unit (straw spreader opening) and winnowing unit was measured separately. The losses of the separating unit (straw cutters) also included the separated grains, which along with the straw, passed over the straw cutters and did not have the opportunity to fall on the sieves and finally fall out of the straw cutters. The losses of the cleaning unit (sieves) included healthy and broken grains that are dumped from the output of the sieves out of the combine.

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| $$P\_{p}= \frac{W\_{q}×10}{Y\_{t}×n×A\_{k}}×100-P\_{n}$$ | (8) |

Where, *Pp* is the processing unit losses (%), *n* is the number of framing times (kg/Ha), and *Wq* is the total weight of grains collected in the box (gr).

Figure 4. Processing unit loss Measurement

* + - 1. **Overall losses of the machine**

The total losses of the combine harvester (HL) were equal to the total losses resulted from the header of the combine,the cutting platform and the losses of the end of the combine (thresher, separator, and cleaner) and were calculated using Equation 7.

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| $$HL=P\_{n}+P\_{i}+P\_{p}$$ | (9) |

Table 1. Details of losses in paddy combine harvesters\*

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| Type of loss | Performance (%) Based on ISIRI 14927 |
| Pn; Maximum natural shatter | 0.5 |
| Pi; Maximum shatter from the header (collecting loss) | 0.5 |
| Pp; Maximum loss of processing unit (blower, thresher, separator, straw walker spreader) | 3.0 |
| HL; Maximum total loss of the machine | 3.5 |

\* According to the Iranian National Standard

* 1. **Statistical Methods**

For statistical evaluation and comparison of rice combine performance, utterly randomized design method and Duncans' average comparison method at a significance level of 5% were used. Thirteen types of combines were defined as experimental treatments. Combines were also statistically compared in terms of 14 measured criteria. Since ranking of the combines was different according to each criterion, all the combines were finally ranked by the TOPSIS method.

1. **Results and discussion**

The results of comparing the mean values ​​of evaluation parameters of rice harvesters using the least significant difference method at the level of 5% probability are given in Figure 5. As the results show, the average percentage of broken grains for the thirteen combines investigated is significantly different at the 5% level (Figure 5a-). Significantly, the lowest percentage of broken grains belongs to the Delta2300 combine, and the percentage of broken grains for other combines is more than 0.22. The highest percentage of broken grains is related to DC-70G and 4LZ-5.0QB combine, approximately equal to 0.30%. Based on this, the average percentages of grains broken by combine harvesters can be calculated for DELTA2300, CX585G, 4LZ-4.6, 4LZ-4.0ZD, TH750C, 4LZ-3.0, 4LZ-4G1, 4LZ-2.5, respectively. AU201-B, 4LZ-2.0B, 4LZ-4.0, 4LZ-5.0QB and DC-70G were 0.09, 0.22, 0.24, 0.25, 0.26, 0.27, 0.27, 0.27, 0.28, 0.29, 0.30, and 0.30%. The results of comparing the average percentage of peeled grains (Figure 5b-) show that combine harvesters fall into five significant groups. The average percentage of peeled grains of combine harvesters is 4LZ-2.5, CX585G, 4LZ-4.0, 4LZ-4.6, 4LZ-4G1, DELTA 2300, 4LZ-4.0ZD, DC-70G, 4LZ-3.0, 4LZ-5.0, respectively. QB, TH750C, AU201B, 4LZ-5.0B which are equal to 0.25, 0.25, 0.25, 0.26, 0.28, 0.28, 0.28, 0.28, 0.30, 0.30, 0.30, 0.31, 0.31. The results of comparing the average of cracked grains show that rice harvesters can be divided into five significant groups. the lowest and highest average values ​​of cracked grains equal to 0.28 and 0.19%, respectively, belongs to the AU201-B and DELTA2300 combines. The results of comparing the mean of unbound clusters show that the 4LZ-5.0QB combine with an average of 0.13% has the highest significant difference with the others. In addition, the TH750C and 4LZ-3.0 combines had the lowest percentage of undamaged clusters. Comparison of the average straw in the grains shows that 13 examined combine harvesters are categorized under seven significant groups. Combine 4LZ-2.5 with an average of %0.2 had the highest, and combine AU201-B with an average of %0.11 had the lowest amount of straw. On the other hand, the five combine harvesters 4LZ-2.0B, 4LZ-3.0, 4LZ-4.0, 4LZ-4.0ZD, TH750C did not have a significant difference in terms of the presence of straw (the average of straw in them was approximately equal to 0.16%). The results of comparing the average presence of weeds in the combines’ tanks show that 4LZ-2.5 and DELTA 2300 combines have the highest and lowest amount of weeds. According to this criterion, combine harvesters can be divided into seven significant groups. The other four combine harvesters including DC-70G, CX585G, 4LZ-4.0, and 4LZ-4.0ZD models belong to a significant group with an average of 0.05% weeds. The results of comparing the average presence of hollow and immature grains show that the three combine harvesters including 4LZ-5.0QB, DELTA 230C, and 4LZ-4.6 have the highest significant value with other combine harvesters without any significant difference. Also, 4LZ-2.5 combine with the average percentage of hollow and immature grains equal to 0.22% has the lowest significant amount.

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The degree of purity of grains in the combine tank is one of the crucial parameters in evaluating combines. The result of comparing the average grain purity between 13 combines is shown in Figure 6. As can be seen, the grain purity of all combines is more than 98%. However, there is a significant difference between them at a significant level of 5%. In this regard, 13 combines are in three significant groups. According to the ASAE Yearbook, the total waste rate in combine harvesters is between 1 to 3% (Plant 1997) and the results obtained in this study (excluding natural shedding) of this type of loss are within the scope of this standard. Moreover, colleagues (Kamaruzaman, Ismail et al. 2001) are consistent. The DC-70G and DELTA 2300 combine produces the lowest and highest grain purity, respectively. regarding quality, Safari et al.(1397)’s findings revealed that the grains in combine tanks had the same level of quality and the combine owners made the necessary adjustments for thresher and thresher, separation, and threshing units, and the purity was acceptable (Amini, Rohani et al. 2020). Mean comparison of combine header losses are shown in Figure 6. As can be seen, the 4LZ-5.0QB and DELTA 2300 combines had the highest mean of header losses compared to the other combines that was statistically significant. Also, two4LZ-4.0 and 4LZ-4.0ZD combine harvesters , had the lowest amount of header losses with an average value of 0.24%. Additionally, the results of comparing the average losses in the sieves of combines show that 4LZ-5.0QB, 4LZ-2.5, and DELTA 2300 models had the highest sieve losses, respectively. Also, the 4LZ-3.0 combine had a significantly lower header loss compared to the other combines. The mean difference of sieve drop of four combine harvesters including 4LZ-4.0ZD, DC-70G, 4LZ-2.0B TH750C was not statistically significant at the 5% probability level. Comparing the average percentage of crushing and crushing of the studied combines showed that the two combine harvesters including 4LZ-5.0QB and 4LZ-4.0 had the highest and lowest amount of crushing and crushing, respectively. The results of comparing the average fuel consumption of combine harvesters showed that the models 4LZ-4.6, 4LZ-4.0ZD, DELTA 2300, DC-70G, 4LZ-4G1, 4LZ-5.0QB, TH750C, 4LZ-2.5, AU201-B, 4LZ-3.0, , CX585G had the highest to lowest fuel consumption of 31.20 to 20.95 litters per hectare. The results of comparing the average field capacity showed that the 4LZ-5.0QB combine had the highest field capacity value of 0.60 with a significant difference. In addition, the field capacity between four combine harvesters including 4LZ-2.5, 4LZ-4.0, 4LZ-2.0B, and 4LZ-4G1, which was approximately equal to 0.55, was not significantly different. Also, two 4LZ-4.0ZD and CX585G combine harvesters had the lowest field capacity equal to 0.40 with no significant difference. The result of comparing the average field yield of the studied combine harvesters showed that the DC-70G combine had the highest field yield (92.03%) with a significant difference compared to the other ones. In addition, the 4LZ-3.0 combine had the lowest field yield (76.13%) with a significant difference. The results are consistent with Roy et al.(2001)’s findings, who obtained a field yield of 72% in the combined plant. One of the reasons for high field yields in feed plant combines is higher field capacity. In Whole-feed combine harvesters, less field capacity causes more traffic in the field, and accordingly more time losses.

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As the results of comparing the average performance criteria of the studied combines showed, the priority of the combine was different in terms of different criteria. Therefore, a method should be used to rank combines based on all criteria. Therefore, the TOPSIS method was used for this purpose. Table 4 shows the ranking results and scores of each combine. As can be seen, the DELTA 2300, AU201-B, 4LZ-2.0B combines are three combines, respectively, which are considered as the first choice among the 13 combines by considering all criteria.

Table 4. Ranking results of combine harvesters using the TOPSIS method

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| treatment | Score | Rank |
| DELTA 2300 | 0.69 | 1 |
| AU201-B | 0.66 | 2 |
| 4LZ-2.0B | 0.63 | 3 |
| 4LZ-4G1 | 0.62 | 4 |
| 4LZ-3.0 | 0.59 | 5 |
| TH750C | 0.58 | 6 |
| 4LZ-4.0 | 0.51 | 7 |
| CX585G | 0.50 | 8 |
| 4LZ-4.0ZD | 0.46 | 9 |
| DC-70G | 0.43 | 10 |
| 4LZ-4.6 | 0.41 | 11 |
| 4LZ-5.0QB | 0.39 | 12 |
| 4LZ-2.5 | 0.30 | 13 |

1. **Conclusion**

In this study, the performance of thirteen rice harvesters was evaluated. Criteria such as percentage of broken seeds, peeled seeds, cracked seeds, uncut bunches, straw, weed seeds, percentage of hollow and immature seeds, degree of seed purity, percentage of nose drop, Percentage of sieve drop, percentage of crushing, fuel consumption and field capacity and field yield were used to evaluate the performance of combine harvesters. Comparing the average performance criteria of combine harvesters showed that their performance could be different according to different criteria. Therefore, the TOPSIS method was used to rank combine harvesters according to all combine performance criteria. Accordingly, the combinations can be selected in order of priority: DELTA2300, AU201-B, 4LZ-2.0B, 4LZ-3.0, TH750C, 4LZ750C, 4LZ-4.0, CX585G, 4LZ-4.0ZD, DC-70G, DC- Named 70G, 4LZ-4.6, 4LZ-5.0QB, 4LZ-2.5. Therefore, the DELTA 2300 combine, a whole-feed type, can be introduced as the best combine. Of course, for a more detailed study, the evaluation should be carried out under different climatic conditions with different types of rice.

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