Introduction

Food security is the basis for our way of life, rice is a major food crop for the people of the world in general and Asians in particular; nearly 90% of the world's rice is produced and consumed in this region. Furthermore, rice is a staple food for nearly 2.4 billion people in Asia, rice provides two-thirds of the calories for most Asians with rice-based diets. Current world population is 7.6 billion [1] and expected to reach 9.8 billion by 2050 [2], this increase translates into 28.02% more human mouths to feed, with the greatest demand growth in the poor communities of the world. According to [3], food supplies would need to increase by 60% (estimated at 2005 food production levels) in order to meet the food demand in 2050 increasing productivity and reductions of losses the cereals in general and rice in special could significantly contribute to ensuring a reasonable diet for a growing population over the next 50 years [4]. Thus, reduction of harvesting and post-harvest food losses is a critical component of ensuring future global food security [5]. Volumes of food losses and food waste arising globally each year Figure 1-4 [6]. Food losses refer to a decrease in food quantity or quality in the early stages of the food supply chain, reducing the amount of food suitable for human consumption. The concept of food losses is thereby often related to harvesting activities with the lacking system or infrastructural capacities [7]. Food losses have a direct and negative impact on the income of both farmers and consumers. Food and Agriculture Organization of U.N. predicts that about 1.3 billion tons of food are globally wasted or lost per year [8]. Reduction in these losses would increase the amount of food available for human consumption and enhance global food security [8].
Reducing food losses offers an important way of increasing food availability without requiring additional production resources, and in less developed countries it can contribute to rural development and poverty reduction by improving agribusiness livelihoods. Reducing harvesting losses may effectively and sustainably increase the volume and quality of available food.

Rice is one of the main substances in the world people’s diets and considers as a strategic crop. Moreover, the consumption is increasing due to a sharp population, noticeable losses of agricultural crops, and improvements in nutrition qualitatively and quantitatively. Therefore, any kind of effort to increase production through waste and loss reduction is important [9]. Harvesting is the most important activity to sustain the productivity and quality of rice. Nowadays, combine harvesters have been playing an increasingly important role in modern agricultural production in recent years, they are being employed massively and continuously in harvesting rice in the world.

The performance of combine harvester should work in trend to reduced grain losses in order to produce the highest quality and quantity of rice. Grain losses during harvest represent a direct loss of income for the farmer. Given the significant role food loss reductions could have toward sustainably contributing to global food security, it is important to have reliable measures of these losses [10]. In some countries, it is perceived that the reasonable small grain loss should reach a maximum of 3% of the total crop yield [11]. It is very important to determine total losses qualitative and quantitative and the quality of harvested mass in the rice harvest combines, not only in terms of economic calculation and determination of total yield and the effects of the harvester but also for global food security concern because any small grain losses could affect the world population feeding [12]. The post-harvest system should perform with minimum loss, maximum efficiency and maximum return for all involved.

**Literature review**

There have been many studies and researches about performance of harvester machines such as [13], who determined the patterns for grain for barely passing through the concave and separating grates of an axial-flow combine, and the grain damaged by threshing and separating. [14] studied the threshing efficiency and power consumption for two threshing units; axial flow threshing and tangential flow threshing. In this study, unthreshed grain, broken grain, damaged grain, skinned grain, and power consumption were investigated. To know the exact status of grain breakage and other losses for basmati rice cultivar, a tangential axisial flow threshing cylinder was compared with fully axial flow cylinder for threshing basmati rice Axial Flow Cylinder The thresher cylinder, Tangential Axial Flow, [15] studied the effects of operating factors of an axial flow rice combine harvester on grain breakage, [16] found in their study that the grain moisture content and the rotor speed affect the amount of grain breakage, [17] compared the threshing mechanism of combine harvesters affects damage on the Winter wheat and spring barley grains including tangential and axial threshing mechanisms. It was found, that
the axial threshing system of grain harvesters damaged the grain significantly lower in comparison with the tangential threshing mechanism. [18] studied the behavior of grain separation in a Thai transverse axial flow threshing unit. [19] studied about operating factors of Thai axial rice combine harvesters pertaining to thresh unit losses concerning. [20] conducted a study on a transverse axial rice thrasher and found that the rotor speeds, feed rates, and guide vane inclinations all affected threshing unit losses, and that rotor speed affects grain breakage, the feed rates and guide vane inclinations did not cause any grain breakage. [21] observed – in their study about the transverse axial thrasher for rice- that the increase in rotor speed directly reduced threshing losses and increased grain breakage due to higher impact forces, and yet an increase in feed rate raised the threshing loss, but did not statistically affect grain breakage. [22] reported that in Thai axial thrasher increasing guide vane inclination and decreasing grain moisture content tended to reduce corn shelling losses, whereas rotor speed, feed rate and grain to the material other than grain ratio, did not significantly affect such losses.

[23] investigated unthreshed grain, broken grain, damaged grain, skinned grain and energy consumption in two threshing units; peg-tooth and rasp-bar, using different drum peripheral speeds, different feeding rate, and two moisture levels were used for comparative performance and determine the appropriate working parameters in trials depending on these parameters. [24] studied the design factors of the axial-flow corn shelling unit affecting losses and power consumption. [25] examined the effects of threshing drum speed of an axial-flow thrasher at five levels and paddy moisture content at three levels on the broken and cracked grains. The results revealed that the most broken grains were recorded at highest drum speed and lowest paddy moisture contents, [26] evaluated the suitability and determine wheat losses using combine “NEW HOLLAND TC56”. [27] investigated the causes of low head rice recovery in combine-harvested evaluating four types of conventional and four types of head-feeding combine harvesters. They found that conventional combine harvesters gave the lowest head rice recovery, [28] evaluated effects of four threshing methods namely power tiller-operated, axial-flow thrasher, tractor-type thrasher and combine harvester as a thrasher on unthreshed grain, shattering loss, damaged grain, and broken rice at millling stage. [29] Investigated the header grain losses and quality of the paddy grains with respect to three different levels of cutter bar heights and forward speeds. [30] studied the effects of combine and crop parameters on wheat recovery, three levels of each parameter i.e. moisture content, concave clearance, and feed rate were examined determined the effect of different forward speed and different cutting height of header; threshing cylinder, separation and cleaning, total losses and combine harvester efficiency. [31] evaluated the impact of header, harvester type, and weather conditions on-field losses and milling quality of rough rice. Four popular harvesters equipped with different headers; The header and total field losses of rice were evaluated for each harvester under regular, rainy and windy weather conditions [32], investigated the losses of JD 1165 combine harvester equipped with variable pulley and belt mechanism has tested.

The objective of this study is to evaluate the performance of two types of combine harvesters, conventional combine, and mid-size combine harvesters in terms of reducing grain losses, increasing grain quality and reducing qualitative losses in wet paddy cultivation in Malaysia.

Materials and Methods

The study was conducted for quality evaluation of crop harvesting and grain losses for combine harvesters during harvesting rice were performed in Tanjung Karang Kuala Selangor Malaysia in 60 plots for two seasons during the years 2017-2018, first season from June to November 2017 and the second season from January till June 2018. Investigations included two type of harvesters, the conventional 5m cutting width NEW HOLLAND CLAYSON 8080, 82 Kw@2500rpm combines are equipped with a cylindrical-concave threshing drum system with a total machine weight of 14500kg at its full payload. The new mid-size 2.2m cutting width WORLD STAR WS7.0, 65.62kW@2700rpm combine is equipped with an axial type threshing system with a total machine weight of 4600kg at its full payload. Relative humidity and temperature were collected during harvesting using handheld ANEMOMETER.

Determination of crop parameters

The Crop Parameters consist of plant density per meter square, normal plants height, abnormal plant height, the degree of maturity, grain moisture content, plant standing angle, panicle length and extent of weed per m2. All these were measurements taken before harvesting using a square wooden frame of 0.5m × 0.5m size in 12 different locations in each farm with a total of 60 farms; 30 farms in the first season and 30 farms in the second season. For plant density, all the plant inside the square wooden frame was counted and plant per square meter was determined [33]. For determining the plant height, height from the base of the plant to the top of the latest spikelet on the panicle [34], measurement ten normal plant height and ten abnormal plant height were made in the square wooden frame. Similarly, the length of the plant stalk attached to the ground was measured made in the square wooden frame. Similarly, the length of the plant stalk attached to the ground was measured immediately after harvesting to determine the cutting height. The degree of crop maturity percentage was measured by selecting ten panicles randomly from each frame and measured moisture content using handheld SMART SENSOR AR991 Digital grain moisture meter vochtmeter. Mature grain moisture content ideally is between 20 to 25%, grains should be firm but not brittle when squeezed between the teeth and 80 to 85% of the grains are yellow-colored [35]. To determine plant standing angle degree, ten plants inside the wooden frame was chosen and the angle between the plant base and the ground was measured using a protractor. Ten panicles from each wooden frame were selected randomly and the length of them was measured using a measuring tape, measured
from the base of the lowest spikelet to the tip of the latest spikelet on the panicle as in [34,35]. To determine the extent of weed per meter square, all plants and weed except the paddy inside the wooden frame were calculated and the average per square meter was recorded. Average grain moisture content at the time of harvesting was recorded by taking grain samples from twelve different locations in the test field using handheld moisture meter SMART SENSOR AR991 Digital grain moisture meter vohcmeter, and grain moisture content after harvesting was measured by the same device and by taking 30 readings in the combine grain tank.

Harvester performance parameters

The cutting width of every combine was measured by using a measuring tape for the first two working rows at five random locations in each farm. When the machine work in the middle of the field ten random measures in every farm was taken. As mentioned above, the stubble of the plant cut after harvesting the height at which the rice crop is cut at harvest was determined in twelve different locations with the 0.5m×0.5m wooden frame and ten stubbles height inside each wooden frame were measured. The cutting efficiency (Ec%) was calculated using the following equation [36].

\[
E_c = \frac{H_a - H_b}{H_a}
\]

Where,

- \( H_a \) = height of stand plant above the soil surface before cutting, cm.
- \( H_b \) = height of the stubble after cutting, cm.

The forward speed was calculated as given below:

\[
S = \frac{D}{T}
\]

Where,

- \( S \) = Forward speed, km/h;
- \( D \) = Distance, km and
- \( T \) = Time, h.

Pre-harvest losses were determined by placing the 0.5m×0.5m wooden frame randomly inside the standing plants at twelve different locations in each farm before the combine entered the plots. Loose grains and panicles fell on the ground were collected within the 0.5m×0.5m quadrates and weighed [37], and the percentage of pre-harvest losses was calculated by using the following equation;

\[
\text{Preharvest losses} = \frac{\text{Mass of collected grains, kg}}{\text{Total mass of grains, kg}} \times 100\%
\]

The harvest losses (threshing and cleaning losses) were determined, at twelve different places randomly selected within the harvested area. The area from where the sample was collected was 0.5m in the direction of combine travel using the 0.5m × 0.5m wooden frame. Threshed and unthreshed grain fallen in the metal frame after the machine has run over it was picked up manually, all grains and panicles inside it gathered and weighted [38]. The percentage of harvesting losses computed by the following equation [37,38].

To determine percentage the of whole healthy grain, broken, cracked, husked grains, and the impurities, ten samples of 100g rough rice was taken from the tank of rice combine harvester from each farm and then broken and husked grains and any material other than grain (MOG) were collected and separated manually and weighted, then the whole healthy grains were determined [38,39]. The broken grains, husked grains were determined for quality losses, weed seed, straw or any other material were taken out manually and weighed employing an electric digital balance.

Results and Discussion

Table 1-3 Shows the basic data on the state of the crops of rice on experimental farmer’s paddy fields on which the test of the quality of harvesting of combines NEW HOLLAND CLAYSON and WS 7.0 PLUS has been performed. Crops were upright, without a significant presence of weeds, which significantly facilitate the work of the combine.

Table 1: Technical specification of combines.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Combine</th>
<th>Mid-Size Combine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>CLAYSON 8080</td>
<td>WS 7.0 PLUS</td>
</tr>
<tr>
<td>Cutting bar length m</td>
<td>5</td>
<td>2.2</td>
</tr>
<tr>
<td>Grain tank capacity m3</td>
<td>4.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Threshing type</td>
<td>Conventional concave</td>
<td>Axial flow</td>
</tr>
<tr>
<td>Engine size, Kw</td>
<td>82</td>
<td>75</td>
</tr>
<tr>
<td>Engine rated speed, rpm</td>
<td>2500</td>
<td>2600</td>
</tr>
<tr>
<td>Gear position operation</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Combine theoretical speed km/hr.</td>
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<td>20</td>
</tr>
<tr>
<td>Total weight, kg</td>
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<td>3400</td>
</tr>
<tr>
<td>Traction type</td>
<td>Semi-track</td>
<td>Fully-track</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Combine</th>
<th>Mid-Size Combine</th>
<th>P Value</th>
<th>% Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track ground contact area, m²</td>
<td>2.031</td>
<td>1.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Track ground pressure, MPa</td>
<td>48.303</td>
<td>&lt;20Kpa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Crop parameters of harvesting plots.

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>% Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>CLAYSON 8080</td>
<td>WS 7.0 PLUS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting bar length m</td>
<td>5</td>
<td>2.2</td>
<td>2.26E-08</td>
<td>26.54</td>
</tr>
<tr>
<td>Grain tank capacity m³</td>
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<td>1.6</td>
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<td>58.86</td>
</tr>
<tr>
<td>Threshing type</td>
<td>Conventional concave</td>
<td>Axial flow</td>
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<td></td>
</tr>
<tr>
<td>Engine size, Kw</td>
<td>82</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine rate speed, rpm</td>
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<td>2600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gear position operation</td>
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<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combine theoretical speed km/hr.</td>
<td>16</td>
<td>20</td>
<td></td>
<td></td>
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<tr>
<td>Total weight, kg</td>
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<td>3400</td>
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<td></td>
</tr>
<tr>
<td>Traction type</td>
<td>Semi-track</td>
<td>Fully-track</td>
<td>0.727ns</td>
<td>ns</td>
</tr>
<tr>
<td>Track ground contact area, m²</td>
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<td>1.7</td>
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<tr>
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<td>&lt;20Kpa</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Significant at α = 0.001, **significant at α = 0.01, *significant at α = 0.05 and ns = not significant.

Table 3: Harvesting performances of combines.

Combine harvesting pattern

The two types of combines were operated in circuitous round corner patterns around field border begins at the edge of the field and works toward the center of the field to finish harvesting of the middle area for all plots.

Cutting width

The combine harvesters were consistently operated at the cutting width ranging from 3.8m to 4.8m with an average of 4.40m for the conventional combine, while mid-size cut the plant through width range from 1.7m to 2.2m with an average of 1.81m (Table 3). The conventional combine has a maximum cutting width equal to 4.8m and it performed that in the first two rows going and coming, harvesting the two edges of the field. The mid-size combine harvester was operated at a greater cutting width which equals to the cutter bar 2.2m at the beginning of the harvesting operation along the boundaries rows and at the lower cutting width as the combine harvester began harvesting in a headland pattern in the middle of the field. The mid-size combine harvester performed 59.55% mean cutting width less than the conventional combine harvester, this gave the conventional combine advantage in term of the field capacity and time-consuming to harvest the field, but the mid-size combine could overcome this problem by operating two machines in the field at the same time which lead to performing the harvesting without delaying in the harvesting operation time.

Cutting height

Cutting height was at the highest level in conventional combine harvester with the mean of 55.58cm (44-65.25cm) while in the axial flow combine harvester it was the least with the mean of 45.09cm (32-48cm). Mean cutting height of the mid-size combines harvester is 18.87% less than that of conventional combine harvester Table 3. Cutting height of harvesting operation is the main criterion of efficient harvesting which is a main concern for the farmers to reduce grain losses, the cutting height of the rice crop at harvesting plays a major role in determining the grain yield, which ensures optimum performance in terms of minimizing grain losses and optimizing grain quality [29]. Cutting efficiency of the mid-size combine harvester was 8.76% lesser than that of a conventional combine harvester (58.79 versus 50.03%). Cutting efficiency of the mid-size combine harvester was 8.76% lesser than that of a conventional combine harvester [29]. Found in their field study in Sri Lanka, when the cutter bar height is increased, it is difficult to cut the panicle from the plant completely. Hence, some parts of panicle remain in the plant itself which is also considered as losses. Also cutting height should be optimized and that for very low cutting height affecting the
efficiency of harvesting performance, [40] reported that combine cutting height is set primarily to avoid excessive shattering and unharvested grain. [41] Found in their study of an axial flow rice combine harvester that, the feed rate does not have any effect on grain quality. Also, [20] showed that in an axial flow rice combine harvester, the feed rate does not cause any breakage to grain.

**Harvesting quality**

**Whole and healthy grains:** Quality of threshed mass has been expressed through the percentage and weight content of a healthy grain. Table 4: Quality of collected grains in grain tank of combines.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Combine</th>
<th>Mid-Size Combine</th>
<th>P-Value</th>
<th>% Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight, gm</td>
<td>87.32±1.168</td>
<td>96.47±0.771</td>
<td>1.22E-19***</td>
<td>10.49</td>
</tr>
<tr>
<td>Whole grain</td>
<td>87.32</td>
<td>96.47</td>
<td>1.22E-19***</td>
<td>10.49</td>
</tr>
<tr>
<td>Damaged grain</td>
<td>2.37±0.358</td>
<td>0.72±0.168</td>
<td>3.38E-11***</td>
<td>-69.63</td>
</tr>
<tr>
<td>Empty grain</td>
<td>4.05±0.569</td>
<td>2.18±0.542</td>
<td>1.08E-06***</td>
<td>-46.23</td>
</tr>
<tr>
<td>Foreign materials</td>
<td>6.28±0.619</td>
<td>0.63±0.542</td>
<td>1.01E-20***</td>
<td>-89.96</td>
</tr>
</tbody>
</table>

***significant at α = 0.001, **significant at α = 0.01, *significant at α = 0.05 and ns = not significant

**Damage and broken grain:** (Table 4 & Figure 5). Demonstrates that the average visible broken grain in the conventional combine was 2.37% while in the mid-size combine was 0.72%. The mid-size combine harvester showed 69.63% less mean broken grain than the conventional combine harvester. This result agreed with the findings of [16,42], they found that grain breakage in axial flow cylinder was lesser than tangential threshing system cylinder. The result of our study also confirmed by [17], who found in their study that the conventional combine was damaging the grain more than the axial combine harvester. [16] Found in their study about axial flow rice combine harvester that the grain breakage was from 0.06 to 0.820 percent. [43] Reported that the axial flow machines result in minimum seed damage with higher output and threshing efficiency. They found in their study that the minimum seed damage of axial thrasher against conventional thrasher was (1.10% vs. 2.5%), (1.48% vs 2.2%), (0.15 % vs.1.97%), (0.27% vs 1.79%) and (0.25% vs 2.18%) in green gram, black gram, soybean, chickpea and sunflower crop respectively.

Various studies have shown that rotary threshing and separating combine perform better than the conventional combine. Axial flow combines harvester WS 7.0 PLUS equipped with rotary type thresher which became popular, [44] reported that, rotary type threshing mechanisms have been widely adopted since the 1980s on corn, soybean, and rice, crops that are susceptible the grain damage and may be less affected across a somewhat wider range of rotor speeds [45,46]. [47] reported that an axial threshing unit, which eliminates the straw walkers damages the grain to a certain extent; however, an axial threshing unit offers the advantage of a threefold feed rate increase. [17] Reported that the tangential threshing system is more aggressive.
and it causes a higher level of mechanical damaging of grains while the axial system works more gently and grain is less mechanically destroyed. The rotor speed is less and the concave gap is higher than in conventional combines; that results in more thorough threshing with less damage under most harvesting conditions [39].

Grain damage by rotary separators may be acceptable over a wider range of speeds and separation forces are greater [44]. Compared with straw walkers, rotary separators have high separation capacity within a smaller machine chassis, reduced moving parts and drives, lower vibration, and lower combine weight [48]. [15] showed that there is an opinion regarding the performance of the axial flow machines that the breakage of grain is less than that of the cross-flow machine as decided by [49]. Consequently, there is much to be gained from evaluating axial-flow technology [13]. [43] Reported that an axial flow thresher was designed and developed to maintain the seed quality of major oilseed and pulse crops. Major features of the thresher are a minimum injury to seed, higher seed recovery, and good seed quality, easy feeding. Harvesting operations being done by conventional threshers and combine resulting in high seed damage and threshing losses [50]. [43] Reported that a recent improvement in grain harvesting technology is the incorporation of the axial flow system in combines and threshers. In the axial flow machines, the crop moves spirally between the threshing drum and concave and thus threshed for a longer duration by repeated impact of the threshing pegs at low speed [13]. It results in minimum seed damage with higher output and threshing efficiency. [42] evaluated an axial flow thresher for paddy crop; the broken grain at recommended speed whereas percentage varied from 2.21-2.51 %.

Threshing performance

Thresholding efficiency: Threshing efficiency is the percentage of the threshed grains calculated on the basis of the total grains entering the threshing mechanism. The maximum threshing efficiency of 98.92% was observed by the mid-size combine harvester, while the threshing efficiency of the conventional combine harvester was 97.73% for threshing of paddy grain Figure 7. The axial flow type combines harvester showed 1.23% threshing efficiency performance more than the conventional combine harvester. Similarly, [43] found in their study that threshing efficiency of 99.43 99.60, 99.40, 99.20 And 98.90% were observed by axial flow thresher for threshing of green gram, black gram, soybean, chickpea, and sunflower crop. [13] Reported that the principle of axial flow combine harvester permits multi-stage threshing and grain straw separation, resulting in a high output and cleaning efficiency. [51] reported that in tangential threshing units with rasp bars, the higher cylinder peripheral speeds threshing losses decrease, but grain damage increases. [43] Reported that the axial flow machines result in minimum seed damage with higher output and threshing efficiency.

Separation efficiency: The mid-size combine harvester has the height mean separation efficiency 97.98% while the conventional combine harvester has the lowest mean separation efficiency was 92.64%. The mid-size combine harvester showed 5.45% mean separation efficiency performance more than the tangential combine harvester Figure 7. [44] Reported that rotary separation forces can be 50-100 g or more, orders of magnitude higher than for straw walkers.
Cleaning efficiency

The mid-size combine harvester has higher mean cleaning efficiency than the conventional combine harvester has the lowest mean separation efficiency (98.75 vs 94.79%). The mid-size combine harvester showed 4.17% mean separation efficiency performance more than the conventional combine harvester (Figure 7).

Harvesting losses

Cleaning losses: Table 5 & Figure 8 shows that the minimum grain loss of 1.25% (9.16g/m²) were obtained by the mid-size combine harvester. While the maximum cleaning grain losses 5.38% (36.14g/m²) were obtained under conventional combine harvester. The mid-size combine harvester showed 74.67% less mean cleaning grain losses than that of the conventional combine harvester (9.08 versus 16.13g/m²). Similarly, [15] found that threshed grains losses in axial flow threshing cylinder for two rice varieties were 0.92% and 1.81%. The performance of the conventional straw walker showed that the problem lies in its mechanism performance. The most difficult task of straw walkers is separating residual grains (free or unthreshed) from straw [47].

Figure 8: Cleaning losses of the conventional combine and mid-size combine harvesters.

The performance of the conventional straw walker showed that the problem lies on the straw walker mechanism performance. [47] showed that the most difficult task of straw walkers is separating residual grains (free or unthreshed) from straw. Most separation is taking place about a third of the way along the walkers. Separation at the front end of the walkers is very poor. [52] reported that most separation is taking place about a third of the way along the walkers.

[53] Reported that with rotary separators, the principle separating force is the centrifugal action, compared to gravity only with straw walkers. The centrifugal force field caused by the rotation of the straw mat together with the rotor can be 50 to 100 times that of gravity.

Figure 9: Threshing losses of the conventional combine and mid-size combine harvesters.
Table 5: Harvesting losses of combine harvesters.

<table>
<thead>
<tr>
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</tr>
<tr>
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<td>6.28</td>
<td>0.63±0.110</td>
<td>0.63</td>
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</tbody>
</table>

***Significant at α = 0.001, **significant at α = 0.01, and *significant at α = 0.05

Threshing losses: The mid-size combine harvester has the lowest threshing losses equal to 1.08% (7.94g/m2) and the largest obtained by a conventional combine harvester, reaching to 2.40% (16.15g/m2) Table 5 and Figure 9. The mid-size combine harvester showed 50.8% lesser mean unthreshed grains losses than conventional combine harvester (7.94 versus 16.15g/m2).

[47] Reported that in comparison with tangential threshing units, the axial ones have lower grain losses. The conventional combine harvester has lower separation efficiency than the mid-size combine (92.79 vs 97.72%) this led to limit grain separation and throughput of straw walkers in conventional combines and this one of the main reasons that led to the integral transfer of their function to the axial threshing units [47].

Total grain losses: For the total grain losses, the mid-size combine harvester has 2.37% (17.1g/m2) mean total grain losses, while the conventional combine harvester has 7.78% (51.29g/m2) mean total grain losses (Table 5 & Figure 10-12). In our study, the mid-size combine harvester showed 67.3% less mean total grain losses than the conventional combine harvester (17.10 versus 52.29g/m2), our findings supported by the result of [13] who found that the total grain loss in fully axial threshing cylinder was less (2.58–4.38%) as compared to tangential flow threshing cylinder (5.79–6.46%). Similarly [54], found that the total grain loss in fully axial threshing cylinder was less (0.4-2.4 %) as compared to the tangential threshing cylinder (5.79-6.46 %), also [42] evaluated an axial flow thresher for the paddy crop, they found that the grain loss ranged from 1.53-2.71 % at the recommended speed.

[27] Found in their study in Pakistan that, conventional combine harvesters gave 5-12% shattering losses and 3-7% threshing losses. Our result revealed that the mid-size combine harvester has a lower percentage of grain losses which agreed with [55] who reported that use of axial-flow threshers in tropical producing countries have substantially reduced crop losses an estimated 2 to 5% grain has been saved.

Figure 10: Total losses of the conventional combine and mid-size combine harvesters.

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Figure 11: Mid-size combine harvester WORLD STAR WS7.0

Figure 12: Conventional combine harvester NEW HOLLAND CLAYSON 8080.

[56] Reported that desirable performance of grain harvesting equipment is usually evaluated in terms of least machine losses, lowest grain damage, maximizing crop throughput, and optimal economy. Optimal machine performance involves trading off acceptable machine grain loss levels in the adjustment of threshing and separating equipment while maintaining grain quality for customer specifications.

Conclusion

Nowadays, the combine harvesters are being employed massively and continuously in harvesting rice in Malaysia. All the
conventional combine harvesters operated in Malaysian paddy fields were originally imported from overseas such as European countries and USA. These combine harvesters were designed for harvesting wheat, the structure of rice stem harder than that of the wheat which had reduced the efficiency of combine harvester when it operates in Malaysian paddy fields [57].

Rice crop is too sensitive to harvest operation due to the high percentage of grain losses affecting total yield. Hence, efficient harvesting and its quality of work are the main concern for the farmers and first customer to reduce grain losses and increase the grain quality, the mid-size has the ability to achieve this. [58] Reported in their survey about harvesters in Malaysia that the farmer complained about the amount of harvested grain losses and quality of harvested grain of the conventional combine harvester. A reasonable balance between capacity and grain loss has to be maintained. To sustainably achieve the goals of food security, food availability needs to be increased through reductions in the post-harvest process at farm level [10]. Reduction of postharvest losses benefits farmers, consumers, and the environment; and can have a high impact in improving the nutritional status and financial strength of those who live in developing countries [59-60].

Desirable performance of grain harvesting equipment is usually evaluated in terms of least machine losses, lower grain damage, and maximizing crop throughput. Unfortunately, these are conflicting goals. Optimal machine performance involves trading off acceptable machine grain loss levels in the adjustment of threshing and separating equipment while maintaining grain quality for customer specifications. For specific crop conditions, there is often a “sweet spot” of combine throughput, with enough crop material being processed by the combine so that crop-on-crop threshing minimizes grain damage, but not so much material that separation efficiency is sacrificed, and the crop is lost [43]. Grain damage contains visible grain damage and invisible grain damage that is reducing the quality of grain as it leads to a reduction in the percentage of germination [29]. Broken grain means that organisms can easily penetrate the broken grains so that breakage can lead to difficulties in the storage of the grain, a factor affecting grain quality.

The mid-size combine produced the highest cleanliness and healthy grain which are primary concerns for the market. The mid-size combine made less damage to rice grain as a minimum content of damaged grains was noted in the harvested mass of combine harvesters which cannot be said for working elements of conventional combine harvester because it recorded the most damaged grain.

Because of their advantages compared to the conventional tangential flow combines, axial flow combines have recently been introduced into the consumer market by New Holland, International Harvester, White Equipment, and Allis-Chalmers companies. The advantages are:

- High capacity
- High efficiency of threshing and separation
- Less grain damages
- Smaller size
- Less vibration [14]

Therefore, it is very necessary that an axial flow thresher and threshing unit to be evaluated for rice at different crop conditions in a wide range in the world. Based on the results of the investigated combines harvested mass quality parameters, we can see that the mid-size combines separation devices doing better compared to the conventional combine harvester. The highest average content of whole grain weight was recorded in the harvested mass of mid-size combines and the smallest in the harvested mass of the conventional combine harvester.

By 2025, more than 5 billion of the world’s anticipated 10 billion people will depend on rice as their principal food. Recent projections indicate that the world will need about 880 million tons of rice in 2025 - 92 percent more rice than was consumed in 1992 [10]. The introduction of advanced combine harvesters into the system which would enable deep cutting will help save the losses during harvesting and threshing. Care should be taken to operate the combines to minimize losses because the conventional combine harvesters encounter problems with grain losses and frequent breakdowns. The factors affect directly on the crop quantity and quality losses and efficiency, which in return, influence crop yield, and the total operational cost.

In contrast to conventional combine, the mid-size combine has the ideal threshing unit which produces a perfect threshing of maximum crop throughput, with optimum grain separation and preserving the natural shape and quality of grains and minimizing grain loss.

In summary, and based on these results, that the WS 7.0 PLiIS combine harvester worked better than the combine harvester NEW HOLLAND CLAYSON, with lower losses of rice grain, higher content of whole healthy grain with a significantly lower share of impurities and less damage to the grain kernel in relation to a conventional combine harvester. It is concluded that the mid-size combine harvester is more suitable for rice harvesting than the conventional combine harvester.

Author Contributions
Conceptualization, MODATHER. Methodology, MODATHER and SUHA. Software, MODATHER. Validation, MODATHER. AZMI YAHYA, and SUHA. Formal analysis, MODATHER. Investigation, MODATHER. Resources, AZMI YAHYA,; data curation, MODATHER. Writing—original draft preparation, MODATHER. Writing—review and editing, MODATHER. AZMI YAHYA, and SUHA, visualization, MODATHER and SUHA. Supervision, AZMI YAHYA, NOR MARIA and AHMAD. Project administration AZMI YAHYA.; funding acquisition, AZMI YAHYA.

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Conflict of Interest

Declare conflicts of interest or state. The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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