ADVANCES IN AGRICULTURAL AND FOOD RESEARCH JOURNAL

Original Research Article

Performance Evaluation of a Height Adjustable Mini Combine Harvester

Mohd Taufik Ahmad[1]*, Mohd Khusairy Khadzir[2]

[1]Engineering Research Center, MARDI HQ, Serdang, Selangor, 43400, Malaysia, taufik@mardi.gov.my
[2]Engineering Research Center, MARDI Seberang Perai, Penang,13200 Malaysia, mkhusairy@mardi.gov.my

*Corresponding author: M.T. Ahmad, Engineering Research Center, MARDI HQ, Serdang, Selangor, 43400, Malaysia, taufik@mardi.gov.my

Abstract: Mini combine harvesters have been very popular among paddy farmers. The compact size of the machine, in addition to the axial flow threshing mechanism and the effect of low ground pressure on paddy soil, makes it a potential alternative for efficient paddy harvesting of a height-adjustable mini combine harvester used for harvesting paddy fields. This type of harvester was tested in typical paddy field conditions planted with MR297 variety at MARDI Seberang Perai. The performance tests included measuring theoretical and effective field capacity, field efficiency, soil bearing capacity before and after machine disturbance and machine slippage. The fuel consumption was also recorded. The combined harvesting losses were also measured during the experiment. Results showed that in wet and muddy conditions, the mini combine harvester obtained a theoretical field capacity (TFC) of 1.28 ha/hr, effective field capacity (EFC) of 0.94 ha/hr and a field efficiency (FE) of 73.4%. The average fuel consumption of the mini combine harvester was 25 L /ha. The wheel slippage in wet paddy fields was 2.18% and on farm roads was 1.55%. The mini combine harvester also contributed to producing less ground effects, combined with the use of low ground contact pressure tracks, that caused minimal soil disturbance that would affect the soil hardpan layer. This mini combine harvester produced an average harvesting loss of 2.3% with an average harvesting impurity of 10.65%. The mini combine harvester had enough power to move in typical paddy field conditions, with no soft soil problems. The mini combine harvester was able to turn 360 degrees within a small area, which made it suitable for harvesting in paddy fields. Thus, this mini combine harvester has the potential to be used for paddy harvesting with the ability to not only produce minimal harvesting loss, but also produce less ground contact pressure which can help to manage the soil hardpan layer from being easily damaged.

Keywords: Mini combine harvester; harvesting loss; machine performance; soft soil; paddy mechanization

Received: 31st March 2023
Received in revised form: 27th October 2023
Available Online: 10th November 2023
Published: 11th June 2024

Citation: Ahmad, M. T., Khadzir, M. K. Performance evaluation of a height adjustable mini combine harvester. *Adv Agri Food Res J* 2024; 5(1): a0000405 https://doi.org/10.36877/aafrj.a0000405

1. Introduction

Combine harvesters have been used for paddy harvesting in Malaysian paddy production since the 1970s with more than 1500 units of various types and specifications (Ahmad *et al.*, 2023). Of this amount, only 5% are owned by government service providers while the remaining ones are owned by private service providers.

Mechanisation has been credited with boosting the productivity of paddy production, but it has also been accused of contributing to the development of soft soil conditions. Soft soil conditions are characterised by high compressibility and low strength, with a hardpan layer at a soil depth of 30 cm that measures less than 0.3 MPa (Nordin *et al.*, 2014; Rendana *et al.*, 2017). Soft soil condition is caused by the extensive use of heavy field machinery which damages the soil hardpan layer. The soil hardpan layer is required in paddy fields to support the weight of field machinery, other than to prevent water leakage (Ahmad *et al.*, 2020; Hemmat & Taki, 2003).

Soil hardpan layer damage is claimed to be caused by the usage of high-ground contact pressure pneumatic rubber tyres (Vial *et al.*, 2020). This type of tyre has a small contact area to the ground surface, and when used on tractors and combine harvesters that has a total mass of more than 5000 kg, a big pressure on the soil surface is hence created (Taghavifar & Mardani, 2013). To make matters worse, additional modifications such as the increase of combine harvesters' tank capacity can result in increased weight thereby increasing ground contact pressure (Ahmad *et al.*, 2015).

Wheel slippage, which is caused by traction loss, substantially increases machine-induced soil impacts in the form of horizontal and vertical soil displacement (Schönauer *et al.*, 2021). As a result, larger wheel slippage can affect the mobility and trafficability of agricultural machinery in paddy fields, especially in soft soil conditions. Agricultural rubber tracks are prone to these conditions due to the large contact area with the soil.

Current combine harvesters in Malaysia are mostly reconditioned or refurbished units, where they are imported as scrap metal and rebuilt in local fabrication workshops. These combine harvesters are large, having a combined header width of almost 5 m and some even have a grain tank capacity of up to 3500 kg (Ahmad *et al.*, 2018b; Wagiman *et al.*, 2019). There are claims mentioning that these machines might be the cause of the soft soil problem occurring in Malaysian paddy fields.

An alternative solution to reduce this problem is to use mini combine harvesters. Mini combine harvesters have a smaller combine header of less than 3 m wide, grain tank capacity of not more than 1500 kg and move on a rubber tracks undercarriage. The total weight of the machine will be no more than 5000 kg, which hopefully, be able to replace the large combines weighing more than 6000 kg. The effective field capacity of mini combine harvesters is lower than large combine harvesters (Wagiman *et al.*, 2019).

A different type of mini combine harvester has been recently imported into Malaysia. This uniquely designed combine is equipped with full tracks, except that the mini combine harvester has an active levelling system. The height adjustable, also known as the active levelling system is claimed to have better stability on uneven ground surfaces to improve the working stability of the machine. This system would also help minimise the effect of threshing and separation when on an uneven and rough surface (Hu *et al.*, 2022). This type of machine has not yet been fully tested scientifically and technically in Malaysian paddy fields, hence requires a specific experiment.

The objective of this paper is to evaluate the performance of a mini combine harvester in terms of machine performance, slippage, soil-bearing capacity and harvesting losses.

2. Materials and Methods

2.1 Machine Description

The mini combine harvester was a fully rubber-tracked mini combine harvester with a power rating of 89.5 kW (120 hp) at a rated engine speed of 2500 rpm. The harvester was powered by a direct-injection, vertical, water-cooled, four-stroke turbo-diesel engine. The harvester was 5.3 m long, 2.6 m wide, and 2.77 m high. The harvester was equipped with a dual rubber track system that was driven by a drive sprocket located at the upper front end of the chassis. The rubber track consisted of 2 upper rollers, 6 lower rollers and one idler. Each rubber track was 55 cm wide with 9 cm pitch and had 56 links. This drive sprocket, which was on each side of the undercarriage, could be lifted simultaneously or independently, which would also increase the ground clearance of the main chassis. It was claimed that the chassis lifting mechanism, or Monroe System, could minimise the effect of threshing and separation when on an uneven and rough surface. The dry weight of the combine harvester was 3500 kg. The combine harvester used an axial flow threshing system with a 204 cm long threshing drum with a diameter of 90 cm. The combine harvester's grain tank could be filled up to 1500 kg and could be discharged using an overhead discharge auger.

Table 1. Mini combine harvester specifications

Item	Description
Brand	Thinker
Model	XG100plus
Power Rating kW (Hp)	89.5 (120) at 2500 RPM Engine Speed
Engine type	direct-injection, vertical, water-cooled, four-stroke turbodiesel
Grain Tank Capacity, kg	1500
Unloading Auger speed, kg/s	10
Working width, cm	266
Total weight, kg	3500
Overall length, m	3.69
Overall width, m	1.65
Rubber Track	55cm wide, 9cm pitch, 56 links
Fuel Tank Capacity, L	210

Figure 1. The mini combine harvester

2.2 Experimental Setup

The experiment was conducted in MARDI Seberang Perai using a paddy field area of 2 ha consisting of sandy loam soil. The plot was filled with water due to overnight rain. The paddy fields were at the optimum harvesting period and planted with paddy of MR297 variety. The average temperature during the experiment was 32°C with humidity of 73%. The test plots were free of soft soil problems.

The mini combine harvester was calibrated as recommended by the importer. The sieve openings were adjusted using a lever to a desired position and the cleaning fan (blower) opening was also adjusted to a specific position. These settings were performed to minimised the grains from exiting through the rear and to reduce impurities in the grain tank. Due to the wet condition of the paddy field, the importer recommended the use of 2nd gear for harvesting.

2.3 Theoretical Field Capacity

The time taken to harvest each experimental plot was measured using a stopwatch. The harvesting speed was then measured. Theoretical field capacity was obtained by multiplying the working width of the harvester with the average harvesting speed.

Theoretical field capacity (TFC) (ha/hr),

$$TFC = (W\ x\ S) \tag{1}$$

where
W = working width (m)
S= harvesting speed (km/h)

2.4. Effective field capacity

The effective field capacity (EFC) was measured using the time consumed for real work and lost for other activities such as turning, loading or unloading and adjustment depending on the field that has been used.

Effective field capacity (ha/hr),

$$EFC = \frac{A}{T_l + T_p} \tag{2}$$

where
A=Area covered (ha)
T_p= Productive time (hr)
T_l=Non-productive time (hr)

2.5 Field Efficiency (FE)

Machine FE is the ratio of EFC to TFC.

FE (%),

$$FE = \frac{EFC}{TFC} x100\% \tag{3}$$

2.6 Fuel Consumption

To determine the fuel consumption in L/ha of the harvester, the diesel tank was filled completely before starting the harvesting operation. Once a certain number of hectares were covered, the amount of fuel used was calculated by measuring the quantity of fuel needed to refill the tank. This amount of fuel used, in L, was divided by the number of hectares covered to obtain the fuel consumption.

Fuel consumption (L/ha),

$$F_c = (V_{after} - V_{before})/A \tag{4}$$

where
V_{after} = Fuel needed to refill the full tank (L)
V_{before} = Fuel needed to fill the full tank (L)
A = Area covered (ha)

2.7 Slippage

The ratio of the actual travel speed of a vehicle to the theoretical travel speed of its wheel is known as slippage or wheel slip (Schönauer *et al.*, 2021).

Wheel slip (%)

$$WS = \left(1 - \frac{V_t}{V_w}\right) x\ 100\% \tag{5}$$

where
V_t= travel speed (m/s)
V_w= wheel speed (m/s)

2.8 Soil Bearing Capacity

Soil conditions were evaluated by the soil penetration or soil compaction. Readings of soil compaction were taken before and after the passage of the tractor, at the beginning, halfway, and at the end of the test area, with 3 replicates for each sampling area. Two types of soil compaction data were taken, which were soil compaction after the passage of tractors' tracks and no disturbance which acted as the control data. The soil strength was measured up to 80 cm depth using a soil cone penetrometer (Penetrologger, Eijkelkamp, The Netherlands) with a base area of 323 mm^2 (ASABE, 2009). Tracks soil disturbance data was taken. No disturbance data was also taken as control. The results from the soil compaction were analysed using SAS ANOVA (SAS Institute, Cary,USA).

2.9 Harvesting Loss

The sampling area for the selected plot was established by considering the combine harvester's header width, which was 3 m. The length of the sampling area was set to 15 m, which was three times the length of the mini combine harvester. This was done to ensure that the combine harvester had enough room to maintain the intended harvesting speed and that enough time was given for the harvested crop to be processed inside the combine harvester. Once the sampling area was harvested in a forward direction, the combine harvester was reversed for 5 m to gather the combine harvester's header loss. Three 25 cm quadrats were used to collect the combine header losses beneath the combine header, and processing losses were collected at the combine harvester's rear using a jumbo bag mounted at the combine harvester's rear straw exit. Yield collected from the sampling area was measured using a jumbo bag fixed inside the combine harvester's grain tank. This process was repeated three times with different subplots to obtain reliable results.

2.10 Combine Harvester Losses Calculation

Based on previous work by Abu Hassan *et al.* (2012) and Ahmad *et al.*(2018b), the following formula was used to calculate the combine harvester's harvesting losses:

$$\text{Processing Loss, PL (\%)} = a/c \times 100 \qquad (6)$$

$$\text{Combine Header Loss, HL(\%)} = b/c \times 100 \qquad (7)$$

$$\text{Combine Harvester Total Loss, (\%)} = PL+HL \qquad (8)$$

where
a = Total clean grain collected at combine harvester's rear jumbo bag, g
b = Total clean grain collected beneath the combine header, g
c = Total yield collected in the grain tank, g

During harvesting inside the sampling areas, parameters such as travel speeds were measured. In order to compare different harvesting charge methods, one similar speed was used which was 3.6 km/h. After harvesting the sample area, all jumbo bags and netted bags were collected, weighed and recorded.

2.11 Harvesting Impurities

Grain samples were taken using small paper bags from the grain tank from each harvested subplot. From each paper bag, a small number of samples were collected and weighed. It was then cleaned by passing it through an air aspirator to remove any chaff, straw, or other debris. The cleaned sub-sample was then weighed. Any impurities, such as weed seeds, broken kernels, or foreign matter, were hand-picked from the sub-sample and weighed separately. The percentage of impurities in the sub-sample was calculated by dividing the weight of the impurities by the total weight of the sub-sample and multiplying by 100. To estimate the total amount of impurities in the grain tank, the percentage of impurities in the sub-sample was multiplied by the total weight of the grain in the tank. This process was replicated three times for each paper bag.

3. Results and Discussions

3.1. Machine Performance

Table 2 shows the mini combine harvester performance obtained from the experiment. The effective harvesting width of the mini combine header created a TFC of 1.28 ha/hr. with an average harvesting speed of 4.83 ± 0.54 km/hr. The EFC measured was 0.94 ha/hr, which then resulted in a FE of 73.4%. The fuel consumption used by this mini combine was 25.08 ± 7.27 L/ha. These results were in contrast with the ones obtained by Wagiman *et al.* (2019) because this experiment was conducted in a wet condition compared to a dry condition. The difficulty of manoeuvring any agriculture prime mover, including a mini combine harvester, in a wet soil condition heavily affected the performance. Operating in a dry condition will surely improve the harvester's performance.

Table 2. The summary results for machine performance

Performance Evaluation	Results
Effective Working width (cm)	266
Average Harvesting Speed (km/hr)	4.83 (0.54)
Theoretical field capacity, TFC (ha/hr)	1.28
Effective field capacity, EFC (ha/hr)	0.94
Field Efficiency, FE (%)	73.4
Average Fuel Consumption (L/ha)	25.08 (7.27)

Standard deviation in brackets.

3.2 Slippage

Slippage is important in assessing the tractive efficiency and optimal settings of a prime mover. Slippage is used as an indicator to determine the correct tractor weight ballast and operating speed, which can have an effect on performance and fuel efficiency. The slippage of less than 5% was targeted. It was observed that the slippage on farm roads was 1.55%. In wet paddy fields, the slippage was still within the targeted range, 2.18%. As a result, the harvesting operation was smooth and easy to handle by the operator. Turning as much as 360° was easily achieved when inside the plot.

Table 3. The summary for slippage.

Condition	Average Slippage, % (Standard Deviation)
Farm Road	1.55 (0.57)
Paddy field (wet condition)	2.18 (1.06)

3.3 Soil Bearing Capacity

The soil effects after the mini combine harvester passage were not significant (t=1.24,p = 0.217). This showed that the low ground contact pressure of the harvester, which was 0.023 MPa at each rubber track, has minimal effect on paddy fields, even though in wet conditions. Although the working depth of the machine was 30 cm, the graph shows that there was no significant damage to the soil strength at 0 – 30 cm. This mini combine harvester will be useful for fields that are currently without any soft soil condition, as results showed no significant effects. The importer claimed that the active levelling system was able to assist the harvester from problematic soft soil areas by lifting both or individual drive sprockets for about 10cm. This mechanism could help the undercarriage to gather more traction to overcome the soft soil condition. However, this feature was not tested during the experiment because no existence of any soft soil problem.

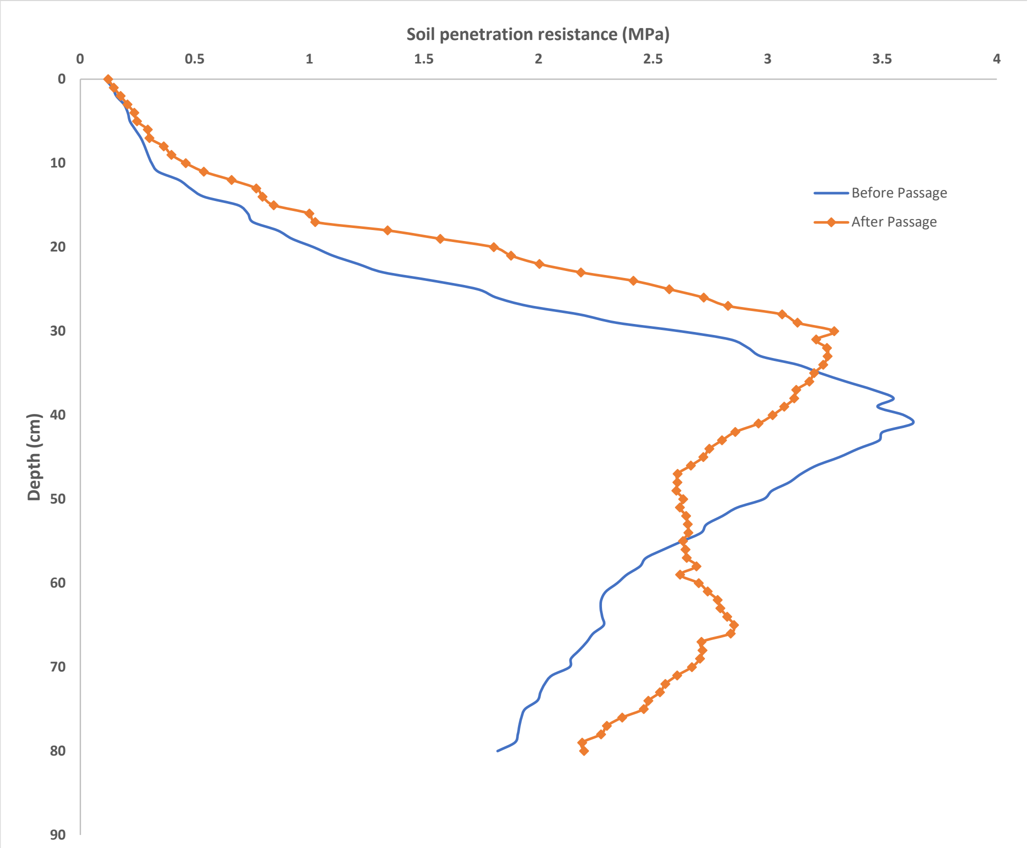

Figure 2. Soil penetration resistance of machine before and after disturbance.

3.4 Harvesting Loss

The experiment conducted showed that the total harvesting loss of the mini combine was 2.3%. Header loss produced a minimal loss of 0.9%. The losses in the processing stage inside the combine, which includes threshing and cleaning, produced a larger portion of the losses, which was 1.4%. The average harvesting speed during the experiment was 4.83 km/hr, which was in the harvesting speed range recommended by MARDI (2018). The feed rate, or throughput of the combine was 6.19 kg/s. These results were similar to the ones reported by Ahmad *et al.* (2018a). Due to the wet condition of the field, the harvesting speed could not be increased. Samples collected inside the rear jumbo bag showed that unthreshed panicles were not present, proving that the threshing process was excellent. However, grains were present inside the rear jumbo bag. This was probably because of the sieve opening adjustments as recommended by the importer. As a result, threshing and cleaning loss contributes the most to harvesting losses compared to header loss.

Table 4. Harvesting Loss of the Mini Combine Harvester.

	Loss, % (Standard deviation)
Header	0.9 (1.7)
Threshing and cleaning	1.4 (0.2)
Total Loss	**2.3 (1.1)**

3.5 Harvesting Impurities

The quality of the harvested grains inside the grain tank was also observed. The average impurities from the harvested grains using the mini combine harvester were 10.65% with a standard deviation of 0.4%. This shows that the settings recommended by the importer were excellent in optimising the quality of the threshing, separating and cleaning process.

4. Conclusions

A height-adjustable mini combine harvester was tested for paddy harvesting in wet paddy fields. The mini combine harvester obtained a TFC of 1.28 ha/hr, EFC of 0.94 ha/hr and a FE of 73.4%. The average fuel consumption of the mini combine harvester was 25 L/ha. The mini combine harvester also contributed to producing less ground effects, combined with the use of low ground contact pressure tracks, that caused minimal soil disturbance that would affect the soil hardpan layer. This mini combine harvester produces an average harvesting loss of 2.3% with an average harvesting impurity of 10.65%. The mini combine harvester had enough power to move in typical paddy field conditions, with no soft soil problems. The mini combine harvester was able to turn 360 degrees within a small area, which made it suitable for harvesting in paddy fields. This mini combine harvester has the potential to be used for paddy harvesting that does not only produce minimal harvesting loss, but also produces less ground contact pressure which can help to manage the soil hardpan layer from being easily damaged.

Acknowledgements: The researchers would like to express gratitude to Wong Engineering Sdn Bhd for providing one unit of Thinker for the duration of the experiment. The researchers would also like to thank the Engineering Research Center staff from MARDI Seberang Perai for their assistance throughout the experiment.

Conflicts of Interest: The authors declare no conflict of interest.

References

Abu Hassan, D., Mohd Shahril Shah, M., Zainuddin, Z., *et al*. (2012). *Combine harvester and combine harvesting loss evaluation technology manual (in Malay)*. MARDI: Malaysia.

Ahmad, M. T., Khadzir, M. K., Md Isa, M. F., *et al*. (2018a). *Harvesting Losses using a Mini Combine Harvester in Sg Acheh, Penang*. Unpublished report.

Ahmad, M., Khadzir, M., Omar, M. (2020). Performance of a triangular rubber tracked tractor in paddy fields. *Advances in Agricultural and Food Research Journal*, *1*(2), 1–7. https://doi.org/10.36877/aafrj.a0000132

Ahmad, M T, Omar, M. F. Z., Khadzir, M. K., *et al*. (2015). Effects of combine harvester tyres and steel tracks on soil compaction. *Proceedings of 7th International Conference of Sustainabke Agriculture for Food, Energy and Industry (ICSAFEI 2015)*, *00*, 0–4.

Ahmad, M. T., Khadzir, M. K., Wan Ahamad, W. M. A., *et al*. (2018b). *Comparison of combine harvesting losses between reconditioned tangential flow combines and axial flow combines in Malaysia*. *2018. Proceedings of National Conference of Agricultural and Food Mechanization*(NCAFM) 2018, 3–5.

ASABE. (2009). Soil cone penetrometer. In *ASABE Standards*.

Hemmat, A., Taki, O. (2003). Comparison of compaction and puddling as pre-planting soil preparation for mechanized rice transplanting in very gravelly Calcisols in central Iran. *Soil and Tillage Research*, *70*, 65–72.

Hu, J., Pan, J., Dai, B., *et al*. (2022). Development of an Attitude adjustment crawler chassis for combine harvester and experiment of adaptive leveling system. *Agronomy*, *12*(3). https://doi.org/10.3390/agronomy12030717

MARDI. (2018). Standard operating procedure to reduce paddy post-harvest losses during combine harvesting. In *Standard Operating Procedure to Reduce Paddy Post-Harvest Losses (in Malay)*. MARDI: Malaysia.

Nordin, M. N., Hamid, A. A., Sharu, E. H., *et al*. (2014). Kaedah penggantian tanah untuk meningkatkan kekuatan struktur tanah di kawasan tanah jerlus. *Jurnal Teknologi*, *70*(6), 45–47. https://doi.org/10.11113/jt.v70.3536

Rendana, M., Idris, W. M. R., Rahman, Z. A., *et al*. (2017). *Effect of Hasil Tani Organic Compound product (HTOC) on the recovery of soft soil in rice field*. *1*(September 2016), 13–20.

Schönauer, M., Holzfeind, T., Hoffmann, S., *et al*. (2021). Effect of a traction-assist winch on wheel slippage and machine induced soil disturbance in flat terrain. *International Journal of Forest Engineering*, *32*(S1), 1–11. https://doi.org/10.1080/14942119.2021.1832816

Taghavifar, H., Mardani, A. (2013). Potential of functional image processing technique for the measurements of contact area and contact pressure of a radial ply tire in a soil bin testing facility. *Measurement: Journal of the International Measurement Confederation*, *46*(10), 4038–4044. https://doi.org/10.1016/j.measurement.2013.07.019

Vial, L. K., Molesworth, A., Lefroy, R. D. B. (2020). Balancing rice and non-rice crops: Managing the risks from soil constraints in Mainland Southeast Asian rice systems. *Field Crops Research*, *246*(November 2019), 107677. https://doi.org/10.1016/j.fcr.2019.107677

Wagiman, N. A., Nawi, N. M., Yahya, A., *et al*. (2019). Field performance comparison of the combine harvesters utilized for rice harvesting in Malaysia. *Food Research*, *3*(2), 177–181. https://doi.org/10.26656/fr.2017.3(2).136