Aquaculture Reports 25 (2022) 101233

Contents lists available at ScienceDirect

Aquaculture Reports

journal homepage: www.elsevier.com/locate/aqrep

Palm date meal as a non-traditional ingredient for feeding aquatic animals: A review

Zulhisyam Abdul Kari [a,*], Khang Wen Goh [b,*], Hisham Atan Edinur [c], Khairiyah Mat [a,d], Hazreen-Nita Mohd Khalid [a], Nor Dini Rusli [a,d], Suniza Anis Mohamad Sukri [a], Hasnita Che Harun [a,d], Lee Seong Wei [a], Muhamad Hakim Bin Mohd Ali Hanafiah [a], Mohammad Mijanur Rahman [a], Mohammad Khairul Azhar Abdul Razab [c], Wendy Wee [e], Nik Shahman Nik Ahmad Ariff [f], Mahmoud A.O. Dawood [g,h,**]

[a] Department of Agricultural Sciences, Faculty of Agro Based Industry, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
[b] Faculty of Data Science and Information Technology, INTI International University, 71800 Nilai, Malaysia
[c] School of Health Sciences, Universiti Sains Malaysia, Health Campus, 16150 Kubang Kerian, Malaysia
[d] Institute of Food Security and Sustainable Agriculture, Universiti Malaysia Kelantan, Jeli Campus, 17600 Jeli, Kelantan, Malaysia
[e] Center of Fundamental and Continuing Education, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu
[f] Razak Faculty of Technology and Infomatics,Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, Malaysia
[g] Department of Animal Production, Faculty of Agriculture, Kafrelsheikh University, 33516 Kafrelsheikh, Egypt
[h] The Center for Applied Research on the Environment and Sustainability, The American University in Cairo, 11835 Cairo, Egypt

ARTICLE INFO

Keywords:
Palm date meal
Plant protein replacement
Nutritional value
Growth and health performance

ABSTRACT

Protein ingredients in aquafeed are one of the most important factors responsible for the development and sustainability of aquaculture. Currently, because of high costs and fluctuating production, some animal and plant protein sources are unable to satiate the increasing demand from the fish feed manufacturers. Aquatic animals' nutritional requirements have been accorded particular focus with less costly feedstuff in aqua feed given extra weightage. There has been increasing attention in recent years on finding methods to recycle the animal and plant by-products for feed preparation. Due to its vital amino acid content as well as high protein composition, palm date meal (PDM) which is a renewable and sustainable resource is expected to be a viable raw material option for replacing protein ingredients (e.g., fish meal and soybean meal) or as a supplement in fish feed. PDM is an agro-industry by-product which left from dates as waste in several countries. This article reviewed the current research including the source, derivatives, and the potential of PDM as a possible alternative to the conventional plant and animal protein sources. Also, the added value of using PDM waste in aquafeed to reduce the feed cost, enhance this e growth rate of fish, improve the health and well-being of fish, and subsequently sustain the aquaculture industry. Therefore, this review paper will illuminate the possibility of PDM as a promising feed source and also the present knowledge and future perspectives about the application of PDM in aquaculture.

1. Introduction

In recent decades, nutrition research in aquaculture has made great strides in identifying alternatives resources for aquaculture feed. It is estimated about 31.5 million tons of farmed fish and crustaceans or 46.1 % of the world's total aquaculture production in 2008 (Andersen et al., 2016; Tacon et al., 2011). The number keep increasing to 62.5 % in 2018 and were projected to reach 172 million tons or 85.4 and 20.7 kg per capita in year 2021 (FAO, 2020) and reaching an annual growth rate 8–10 % annually until 2025 (Tacon et al., 2011). Population growth in the mid-21st century poses significant challenges to the provision of high quality, nutrient rich food.

Currently, aquatic feeds are overly dependent on fishmeal and fish oil extracted from wild-caught forage fish. However, increased use of forage fish is not sustainable and because an additional 37.4 million tons of aquatic feed will be required by 2025 (Hua et al., 2019). Hence, some

* Corresponding authors.
** Corresponding author at: Department of Animal Production, Faculty of Agriculture, Kafrelsheikh University, 33516 Kafrelsheikh, Egypt.
E-mail addresses: zulhisyam.a@umk.edu.my (Z.A. Kari), khangwen.goh@newinti.edu.my (K.W. Goh), Mahmoud.dawood@agr.kfs.edu.eg (M.A.O. Dawood).

https://doi.org/10.1016/j.aqrep.2022.101233
Received 16 September 2021; Received in revised form 10 June 2022; Accepted 19 June 2022

fish nutrition experts have sought to develop feed formulations for aquaculture that support or enhance the growth of farmed fish at cheap cost. Feed manufacturers around the world have started doing some research to replace fishmeal and fish oil in aqua feed (Kari et al., 2021b; Turchini et al., 2019; Zulhisyam Abdul et al., 2020a; Zulhisyam et al., 2020b). Feed formulation is not an exercise to identify "alternatives" or "alternatives" but rather a process to identify various combinations of "complementary" raw materials including fishmeal, fish oil, etc., which collectively meet specific nutrient requirements and other aquatic feed standards (Turchini et al., 2019). Nutrient-based formula is the everyday reality of formulating an artificially formulated hydroponic forage, but this approach focuses more on an alternative source of plant-based feed.

Pheonix dactylifera or commonly known as dates or palms, is a species of flowering plant in the palm family, *Arecaceae*, cultivated for its sweet, edible fruit and pit (Qadir et al., 2020). There are nearly 3000 names of date varieties around the world, and the palm date is one of the first cultivated fruit trees in the world and has become one of the classic fruits of the ancient world along with olives and figs (Zohary and Hopf, 2020). The palm date has always been one of the most important fruit crops in the dry regions of the Arabian Peninsula, North Africa, and the Middle East. After the past three centuries, dates have also been introduced to new production areas in Australia, India, Pakistan, Mexico, South Africa, South America and the United States (Chao and Krueger, 2007). The value of the palm date which is a source of high-energy nutritious fruit that can be eaten fresh and can be easily stored by sun drying and used as a nutritional supplement. The date fruit is very popular all over the world due to its richness in outstanding nutrients and health promoting properties (Abi Sen et al., 2020). Some researchers have used fresh palm kernels and their seeds as protein and energy components in fish feed to enhance feed utilisation efficiency (A. Sotolu et al., 2011).

Dates have been found to have a variety of medicinal uses. It helps prevent the accumulation of lipids in the blood, anticancer, protect the digestive system, prevent damage to the liver, and other activities, making them an essential nutritious food in daily health. Previous studies reported that the pharmacological properties of palm dates could be characterised by the presence of a greater concentration of minerals, including copper, potassium, magnesium, manganese, iron, phosphorus and calcium (Al-Farsi and Lee, 2008; Ali-Mohamed and Khamis, 2004; Baliga et al., 2011). As well as a variety of other bioactive compounds with varying molecular structure (Alharbi et al., 2021). The palm date fruits at various stages of maturity and the seed were widely used for different purposes of cooking, medicine, nutraceuticals, and others.

Date fruits and their derivates such as syrup, paste, powder, puree, flour and oil products could add value to many foods due to their high nutritional value, low glycemic index and potential anti-diabetic and antioxidant properties (Martín-Sánchez et al., 2013). Date seed is regarded as one of the most significant sources of waste during harvest and manufacturing. However, roasted and powdered date seeds are used as coffee alternatives in some remote communities and in coffee-like beverages in the middle east (Baliga et al., 2011)On the other hand, the date seed oil is notable for its high concentration of mono-unsaturated fatty acids, mainly oleic acid. It is a good source of lipid-soluble antioxidant compounds like phenols, tocopherols, and phytosterols, which help to lower the risk of various diseases. With the vast amount of date seeds, which are a troublesome waste product, oil extraction may be financially viable and should be taken into consideration for future investment (Mrabet et al., 2020).

Although palm date tree cultivation yields considerable amounts of date fruit, its often accompanied with significant amount of discarded waste in form of seeds and fallen fruits which estimated around 20 % of total date fruit production (Debache, 2021). In the light of the high availability of palm date meal (PDM) this review article is planned to present an overview on the current research including the source, derivatives and the potential of PDM as a possible alternative for the traditional plant and animal protein sources. Also, the added value of using PDM waste in aquafeed to reduce the feed cost, enhance the growth rate of fish and sustain aquaculture industry. Therefore this review paper will illuminate on the possibility and effect of PDM as promising source and also present current knowledge and future perspectives about the application of PDM in aquaculture.

2. Source, forms, and derivatives of PDM

PDM are produced from the date fruit waste and date seeds collected during the harvesting, storage, conditioning, and processing stage of date fruit production (Debache, 2021). Date fruit waste comes in various forms including flesh, seeds and mixture of flesh and seeds. The date flesh waste contains the skin (epicarp) and pulp (mesocarp) while leaving behind the thin membranous layer (endocarp) and seeds (endosperm) which contains the kernel and pit (Fernández-López et al., 2022; Ghnimi et al., 2017; Sakr et al., 2010). Fig. 1.

Date flesh waste can be categorised into various derivatives such as paste (Martín-Sánchez et al., 2013), syrup (Gad et al., 2010; Jridi et al., 2015), puree (Di Cagno et al., 2017), abandoned and unripe fruits (Kulkarni et al., 2010); while the date pits or seeds are commonly derived into flour (Ambigaipalan and Shahidi, 2015), powder (Baliga et al., 2011), aqueous extract (Diab and Aboul-Ela, 2012), and oil (Basuny and Al-Marzooq, 2011; Nehdi et al., 2010). The mixture of flesh and pits which commonly been regarded as the PDM are usually derived in the forms of powder and puree which often been used in animal feeding (Elgasim et al., 1995). Table 1 compares the application of derivatives of palm dates waste on different purposes and the observation from the application.

3. Nutritional and chemical composition of PDM

Date fruits contained a good source of sugar (around 70–80 % sugar content), depending on the species and maturity stage of the fruits likes glucose, fructose, and sucrose which are easily absorbed by the body to provide energy (Zhang et al., 2015). The average protein content has been recorded to be 1.22–3.30 %, fat 0.11–7.33 %, ash 1.43–6.20 %, and carbohydrates 65.7–88.02 % (Benmeziane-Derradji, 2019; Chai and Isa, 2013). However, according to Alharbi et al. (2021) stated that the protein content decreases during the non-enzymatic browning and tannin precipitation stage. Date fruits contain all essential and non-essential amino acids, particularly glutamic acid, lysine, alanine, serine, aspartic acid, proline, and glycine. At the same time, the fatty

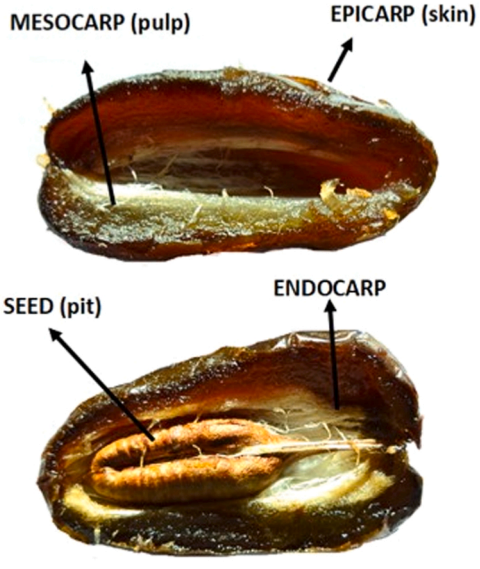

Fig. 1. The anatomy of palm date fruit.
Source: Fernández-López et al. (2022).

Table 1
The source and derivatives of PDM with their application on different purposes.

Source	Derivatives	Application	Observation	References
Flesh	Paste	Cooking ingredients	Date paste added to pork liver pate protected it from lipid oxidation and made it more appealing to the sense of taste.	Martín-Sánchez et al. (2013)
	Syrup	Sweetening agents	Syrup polysaccharides contribute to better maintain dairy dessert texture as well as enhanced apparent viscosity and reduced syneresis. Natural antioxidant agents lead to improve functionality.	Jridi et al. (2015)
		Yogurt	Yogurt infused with 10 % date palm syrup seems to have a smooth texture, a moderately sour and delightful flavour, and contain a high nutritional value.	Gad et al. (2010)
	Puree	Functional dietary supplement	Fermenting date fruit puree with specific Lactobacillus plantarum strains resulted in the highest concentration of c-amino butyric acid, conjugated fatty acids, and insoluble dietary fibers.	Di Cagno et al. (2017)
	Abandoned and unripe fruits	Concentrated juice	After 6 months of storage, the juice concentrate was stable and could be reconstituted to make ready-to-serve beverages with acceptable sensory quality.	Kulkarni et al. (2010)
Seed	Flour	Bakery products	Muffins' total dietary fibre and ash content increased and improved the antioxidant activity.	Ambigaipalan and Shahidi (2015)
	Powder	Animal feed	has no negative side effects on animals	Baliga et al. (2011)
		Drink	The seed powder is marketed and is a popular option for people who prefer a non-caffeinated coffee with a coffee-like flavour.	Baliga et al. (2011)
	Aqueous extract	Drink	Shows the anti-genotoxic activity and reduce DNA damage induced by N-nitroso-N-methylurea in mice.	Diab and Aboul-Ela (2012)
	Oil	margarine	Carotenoids are sufficient for margarine production as they provide a natural yellowish butter-like colour without the addition of synthetic colourants.	Nehdi et al. (2010)
	Oil	mayonnaise	superior sensory characteristics compared with the control	Basuny and Al-Marzooq (2011)
Flesh and seed	Powder and puree	Animal feed	Improve the gonadotropic activities by enhancing the production of FSH, LH, oestrogen and testosterone thus, uplift the spermatogenesis, sperm count, and growth.	Elgasim et al. (1995)

acids (0.2–0.5 %) and vitamin contents recorded in date fruits was low (A Golshan Tafti et al., 2017). Interestingly, the content of B-complex vitamins was observed to be high in date fruits (Siddiq and Greiby, 2014). Dates contain 1.9–16.95 % dietary fiber, out of which insoluble fiber is recorded as 84–94 %, and soluble fiber content ranges between 6 % and 16 % (Alghamdi et al., 2018). Dietary fiber has important therapeutic effects, and the fiber concentration also depends on the variety and stage of maturity (Juhaimi et al., 2012). PDM contained a high amount of minerals (i.e. selenium, magnesium, potassium, calcium and phosphorus) and a high nutritional value and health benefits have long been demonstrated for date flesh (Al-Farsi et al., 2005; Dawood et al., 2020a) and it is also rich in antioxidants and phenolic compounds (Akbarzadeh et al., 2019). According to Jaganathan et al. (2018) indicated that PDM consists numerous favourable properties such as antiviral, antibacterial, and antifungal activity. Furthermore, the elemental fluorine and selenium found in date fruit can protect teeth and stimulate immune function in humans. In addition, dates contain 1–2% phenolic antioxidants, tannin-based pigments, and epicatechin oligomers.

PDM are a good source of phytochemicals such as phenols, sterols, carotenoids, anthocyanins, procyanidins, and flavonoids (Tang et al., 2013). They are also rich in dietary fiber (67.56–74.20 %), with water-insoluble mannan fiber found at a high percentage. The contents of proteins, vitamins, fatty acids, and minerals were reported to be high in the date seed (Table 2). Insoluble dietary fibers (hemicellulose, cellulose, and lignin) are the main components of seed fiber (Shafiei et al., 2010). Date seeds contain many dietary minerals such as potassium, copper, magnesium, calcium, cadmium, chromium, iron, manganese, zinc, nickel, cobalt, calcium, phosphorous, and lead; the potassium levels were reported to be high (229–293 mg/100 g) (Assirey, 2015; Besbes et al., 2004; Golshan Tafti et al., 2017; Ogungbenle, 2011).

The concentration of minerals in dates increases with maturity in some varieties, such as in the Deglat Noor variety. Other studies have found that the mineral concentration decreases when the dates in five other varieties are ripened (Tang et al., 2013). The fatty acid content in the seed varies from 53.2 % to 58.8 %, which includes eight types of fatty acids (Golshan Tafti et al., 2017). They are a good source of unsaturated fatty acids, oleic acid (42.3 %), and linoleic acid (13.7 %). In contrast, the saturated fatty acids, viz., palmitic acid (9.6 %) and lauric acid (21.8 %), were reported at minimal concentrations (Al-Shahib and

Table 2
Nutrient compositions of date fruit and seed (* g/100 g; # mg/100 g).

Component	Date fruit	Date seed	References
Moisture *	9.43–21.53	8.64–12.25	(Alghamdi et al., 2018; Borchani et al., 2010; Habib and Ibrahim, 2009)
Protein *	1.22–3.30	4.81–5.84	(Alghamdi et al., 2018; Borchani et al., 2010; Habib and Ibrahim, 2009)
Fat *	0.11–7.33	5.71–8.77	(Alghamdi et al., 2018; Benmeziane-Derradji, 2019; Habib and Ibrahim, 2009)
Ash *	1.43–6.20	0.82–1.14	(Benmeziane-Derradji, 2019; Borchani et al., 2010; Habib and Ibrahim, 2009)
Carbohydrate *	65.70–88.02	2.43–4.65	(Benmeziane-Derradji, 2019; Golshan Tafti et al., 2017; Mohamed et al., 2014)
Dietary fiber *	1.90–16.95	67.56–74.20	(Alghamdi et al., 2018; Benmeziane-Derradji, 2019)
Magnesium #	56–150	51.70–58.40	(Assirey, 2015; Besbes et al., 2004)
Calcium #	123–187	28.90–38.80	(Assirey, 2015; Besbes et al., 2004)
Phosphorus #	12–27	83.60–68.30	(Assirey, 2015; Besbes et al., 2004)
Potassium #	289–512	229–293	(Assirey, 2015; Besbes et al., 2004)
Sodium #	4.90–8.90	10.25–10.40	(Assirey, 2015; Besbes et al., 2004)
Iron #	0.30–2.20	2.30–2.21	(Besbes et al., 2004)

Marshall, 2003). In addition, fruit pulp and seeds contain other fatty acids such as myristic, stearic, and linolenic acids. The predominant fatty acid recorded at a high level was oleic acid, and the levels varied among the species (Besbes et al., 2004). The advantage of the seed oil is that it has a dark yellowish hue compared to the vegetable oils.

4. Application of PDM in aquaculture nutrition

The date seed is rich in protein, fat and dietary fiber that make it suitable as ingredients in feed for aquaculture species (Abolfazl Golshan Tafti and Panahi, 2019). Many studies involving PDM were directed towards utilisation of date seed meal as replacement of carbohydrate. Supplementation of PDM as feed additive was carried out on juvenile African catfish, *Clarias gariepinus* has improved growth performance and feed utilisation (A. O. Sotolu et al., 2014). PDM was also studied on common carp *Cyprinus carpio* L. (Ahmed et al., 2017) and tested on Gilthead Seabrea (*Sparus aurata*) diets and Nile Tilapia (*Oreochromis niloticus*) (Azaza et al., 2009; Belal, 2008; Gaber et al., 2014a, 2014b) (Table 3).

Several treatments have been carried out on the date seed meal to improve efficiency of utilising the feed. The fermentation process of date palm seed by *Aspergillus oryzae* and yeast (*Saccharomyces cerevisiae*) in dietary PDMs had improved the composition of potential crude protein and crude lipids in the untreated meal (Table 5) (Dawood et al., 2020a, 2020b; Dossou et al., 2018; Hong et al., 2004). Moreover, these fermented PDMs have revealed significant increase in amino acids values that essential for fish intestinal health (Table 5). The increments of amino acids composition are believed due to break down of protein during fermentation process into soluble form in fermented PDM which can be easily absorbed by fish.Study by Dawood et al. (2020a) reported application of fermented PDM using *Aspergillus oryzae* at 103.3 – 164.7 g/kg diet could increase growth, digestion activity and immune response of Nile tilapia (*Oreochromis niloticus*). In another paper by Dawood et al. (2020b), used PDM enhanced with application of *Saccharomyces cerevisiae* as probiotics to increase the acceptance of Nile Tilapia towards PDM. Many studies also enhance the efficiency of PDM using fermentation process using various fungi and bacteria probiotics

Table 3
The study on PDM in different aquatic species.

Species	Inclusion levels of PDM (%)	References
African catfish (*Clarias gariepinus*)	1.50	Sotolu et al. (2014)
Common Carp (*Cyprinus carpio*)	0.5	Ahmed et al. (2017)
Nile tilapia (*Oreochromis niloticus*)	20–30	Azaza et al. (2009)
Nile tilapia (*Oreochromis niloticus*)	15	Belal (2008)
Nile tilapia (*Oreochromis niloticus*)	15	Gaber et al. (2014b)
Nile tilapia (*Oreochromis niloticus*)	30	Gaber et al. (2014a)
Nile tilapia (*Oreochromis niloticus*)	10.33–16.48	Dawood et al. (2020a)
Nile tilapia (*Oreochromis niloticus*)	11.44–17.44	Dawood et al. (2020b)
Pacific white shrimp (*Penaeus vannamei*)	10	Akbarzadeh et al. (2019)
Fingerling common carp (*Cyprinus carpio*)	10	Kamali-Sanzighi et al. (2019)

Table 4
Chemical composition of PDM and fermented PDM.

Composition (%)	Date seed meal (Dawood et al., 2020a)	Fermented date seed meal by *A. oryzae* (Dawood et al., 2020a)	Fermented date seed meal by yeast (Dawood et al., 2020b)
Crude protein	8.13	9.54	8.75
Crude lipids	2.02	2.48	2.92
Ash	5.44	4.21	4.54
Crude fibres	6.73	4.31	6.00
Gross energy (kcal/kg)	384.08	403.94	396.76
Total antinutritional factors (ANFs) (mg/kg)	3.17	2.03	n/a
Amino acid (%)			
Arginine	3.51	4.60	4.32
Histidine	1.91	2.02	2.11
Isoleucine	2.41	3.52	2.87
Leucine	4.72	5.41	5.21
Lysine	2.51	3.10	2.85
Methionine	1.31	1.91	1.83
Phenylalanine	2.92	3.62	3.44
Threonine	2.11	2.92	2.67
Tryptophan	2.30	2.60	2.51
Valine	3.62	4.41	4.21

(Assem et al., 2014; Belal, 2008; Moustafa et al., 2020). Application of PDM was also carried out on shrimp species. A study by Akbarzadeh et al. (2019) was carried out on the pacific white shrimp to determine the effect of dietary PDM as an alternative carbohydrate. Result from this study showed great potential of utilising PDM without reducing its performance. In conclusion, previous studies show great potential of application of PDM to improve growth as well as immune response of the targeted aquaculture species.

5. The effect of PDM on the growth performance

In fish production, growth performance is the most important economic factor in their production. Several trials were conducted to investigate the possibility of using PDM to replace FM in aquatic animal diets including Nile tilapia (Assem et al., 2014), African catfish (Sotolu et al., 2014), common carp (Ahmed et al., 2017; Hoseinifar et al., 2017; Kamali-Sanzighi et al., 2019; Mohammadi et al., 2018) and Pacific white shrimp (Akbarzadeh et al., 2019). It was reported that date palm seed

Table 5
The recommended inclusion levels of PDM in fish feed.

Fish	Treatment	Recommended level (%)	References
African catfish	–	1.50	Sotolu et al. (2014)
Tilapia	–	10.30–16.50	Dawood et al. (2020b)
Nile tilapia	–	15	Belal (2008)
Tilapia fingerlings	Fungi Trichoderma reesei -degraded date pits	30	Belal (2008)
Nile tilapia	Date pits with additives (Digestarom® or Marjoram leaf extract)	13.50	Mabrouk et al. (2011)
Tilapia fry	Isonitrogenous and isocaloric diets with inclusion of dates and date pits	15 % date pits could be incorporated in fish diets for obtaining less-fatty fish.	Al-Yousef et al. (1985)
Nile tilapia (fingerlings)	Isonitrogenous- isocaloric rations containing 0 %, 15 %, 30 % and 45 % of wasted date	The diet containing 30 % date was superior to all other test diets.	Belal and Al-Jasser (1997)
Juvenile and adult Nile tilapia	Date pits replaced wheat bran in the Isonitrogenous- isocaloric test diets at 0 %, 25 %, 50 %, 75 % and 100 % substitution levels.	Date pits-based diets at all inclusion levels exhibited retardation in growth rates and feed utilisation efficiency but cost effective.	El-Sayed et al. (2006)

meal fermented with *Aspergillus oryzae* (ASP) at 103.3–164.8 g/kg diet can be used effectively in tilapia diets for improving the growth performance of Nile tilapia (Dawood et al., 2020a). In their study, the used fermented date seed meal (DSM) and considered the low price of DSM and very recommended to the aquaculture industry. Furthermore, another study indicated that the inclusion of PDM have a positive effect on growth performance of common carp (Ahmed et al., 2017). In their study, the result showed that weight gain (WG) and specific growth rate (SGR) with the inclusion of 5 g date palm seed per kg diet were significantly higher compared with others treatment.

The study by Kamali-Sanzighi et al. (2019) reported the improvement of growth performances at nearly a similar inclusion level (100 g/kg diet) for common carp fed with PDM. Similarly, beneficial effects were achieved by higher levels of DSM (100 g/kg) in Pacific white shrimp Akbarzadeh et al. (2019) and by lower levels in common carp (50 g/ kg) (Mohammadi et al., 2018). However, African catfish fed diets supplemented with PDM showed significant effects on the growth performance parameters at 15 g/kg diet (Sotolu et al., 2014). The level of giving maximum growth performance may vary according to the DSM processing method, period of administration, experimental procedures and fish species and sizes (Dawood et al., 2020a).

The inclusion level of plant protein to the fish feed is a very crucial parameters that to be researched. According to Dawood et al. (2020a), significant decreases in growth performances in Nile Tilapia after fed with fermented palm dated meal at 200 g/kg. This is because the date palm seed meal has a high fibre and ANF contents, which may negatively affect the feed efficiency of fish and growth performance. According to Mohammadi et al. (2018) indicated that high levels of date seed meal have been shown to reduce weight by increasing both the metabolic rate and energy expenditures while decreasing the digestibility of ingredients because of its content of some ANFs, such as of tannins, catechin monomers and caffeine. Date seed meal polyphenols have been found to exert their influence upon the emulsion interface, interacting with digestive enzymes to decrease feed utilisation and weight gain (Sotolu et al., 2014). Besides that, the study by Kamali-Sanzighi et al. (2019) showed that growth performances were improved by substitution of plant sources of 10 % waste date compared with others treatment for fingerling Common carp (Cyprinus *carpio*).

6. The effect of PDM on the feed utilisation and digestibility

The PDM in the ration is considerably valuable in improving the feed utilisation in fish and the recommended inclusion levels are shows in the Table 4. El-Sayed et al. (2006) observed that the incorporation of raw date seeds in Nile tilapia diets lead to poor feed utilisation. In another study, Mabrouk et al. (2011) reported that the using of wet cull date (WCD) (13.5 %) instead of yellow corn (YC) in tilapia zero-additives based diet increased the tilapias' feed utilisation, although replacement with dry culled dates or date pits decreased tilapia feed utilisation (compared with yellow corn), and dried date seeds gave the worst performance; another study concerning tilapia mentioned that the inclusion of fermented date palm seed meal at 103.3–164.8 g/kg in tilapia's diet is effective in improving digestion, this occurring because the dietary fermented date palm seed meal significantly increased the lipase, amylase and protease activities in the diet (Dawood et al., 2020a); supporting this statement, El-Sayed et al. (2006) hypothesised that the carbohydrates in date seeds may contain amylase inhibitors or other antinutrients that reduce the date seeds' utilisation by tilapia. In a similar study, Belal and Al-Jasser (1997) reported that the total replacement of corn starch with date by-product improved tilapia feed conversion and protein efficiency ratio. Mabrouk et al. (2011) also mentioned that the nutrient utilisation of date seeds improves by the use of additives such as Digestarom® and Marjoram leaf extract. Another study regarding a variety of the tilapia species, Yousif et al. (1996) reported that the nutrient utilisation of blue tilapia (*O. aureus*) fed date-based and date-seeds-based diets was very poor. In another species of fish, common carp, Al-Asgah (1988) found that date seeds can replace wheat bran-barley mixture up to 75 % in common carp feed without any negative effects on feed utilisation efficiency. In yet another species, Sotolu et al. (2014) observed that when 1.5 % date seeds meal was included in African catfish diet, the nutrient utilisation efficiency of the fish augmented the most among the other date seed levels and the control diet. From this observation, they claimed that the date seed has the potential to improve the digestion of feed which in return gives more effective nutrient utilisation without any harmful effects. In another study, Sotolu et al. (2011) claimed that date seeds are the best energy source for increasing feed utilisation efficiency for aqualife. The above results indicate that the condition of the date seed is of significant importance when adding to the fish ration as it affects the feed utilisation, and the best addition to tilapia ration is the wet culled date with additives and the amount of date seeds added should be only up to 15 %. It is also indicated that the types of condition of the date seeds affects different species of fish differently. Okanlawon and Oladipupo (2010) observed that low fibre content of feeds in fish ration can stimulate increased feed intake as well as enhance feed quality and digestibility. This study is in line with the findings of Dioundick and Stom (1990) who observed that tilapia grow extremely well when there is only up to 5 % fibre in the tilapias' ration. To conclude, date seeds are an effective organic-based plant-based by-product to include in fish diets and can potentially replace other products like yellow corn, corn starch, and additives without any decline in nutrient utilisation and digestibility. Since there are limited research regarding the nutrient utilisation and digestibility of date/date seeds when consumed by fish, more research must be made to fully understand and effectively utilise this by-product.

7. The effect of PDM on the carcass composition

Body carcass composition is very important in feed nutrient studies

and it is also one of the indicators to test the efficiency of the new feed proposed. Recently, the available data on the effect of PDM regarding carcass composition on fish is very limited. The study by Sotolu et al. (2014) showed that the improvement of fish carcass composition when fed with date palm seed followed the trend in fish SGR, FCR, PER and PPV since nutrient utilisation consequent to high digestibility value has been directly linked with final fish carcass composition. These results may be supported by the postulation from Lara-Flores et al. (2003) who found that the Protein Efficiency Ratio and Apparent Protein Utilisation recorded the best values with probiotic-supplemented diets in fish as feed additive. With the improvement in science and technology, fermentation has also been reported to be viable as a technique to reduce undesirable components and enhance the nutritional quality of a by-product to get another product (Kari et al., 2021a; Shi et al., 2015) and can enhanced the carcass composition of fish.

8. The effect of PDM on the intestinal health and bacterial diversity

The fish ration with fermented PDM offers higher composition value of arginine (4.3 – 4.6 %) that essential to enhance intestinal enzyme activity and changes the microbiota composition and their activity in the gut (Andersen et al., 2016; Eid et al., 2015). This has supported by the findings on digestive enzyme activity involves lipase, amylase and protease which their activities in Nile tilapia were shown to be boosted when the fish was fed with varies concentrations of fermented PDM (Dawood et al., 2020a; Golshan Tafti et al., 2017). Besides arginine, PDM also provide large amount of glutamic acid which its derivatives, glutamine and glutamate play a vital functions in modulating intestinal structure and protects the intestine from oxidative damage (Andersen et al., 2016; Bouaziz et al., 2008). The study by Dawood et al. (2020a) also highlighted observation on fish intestinal sections which displayed enlargement in nutrition absorption area on villi surfaces indicated that fermented PDM by *A. oryzae* had positive impact on fish intestinal absorptive capacity. Similar findings also has been documented when fish was fed with yeast-fermented PDM (Dawood et al., 2020b).

Apart from enhancement of fish intestinal structure and morphological changes, dietary supplements also influence the diversity of microbial community in the intestine (Jang et al., 2019; Wang et al., 2018). The gastrointestinal tract of fish consists of a diverse microbiota that play essential role in fish nutrition and health. The balance of bacterial community in fish intestine holds crucial responsibility in digestion, absorption and metabolism of the fish (Jang et al., 2019). The microbial diversity is varies in different species depending on the culture environment and fish diet (Nayak, 2010; Wang et al., 2018). Fermentation process involves in the preparation of dietary PDM can promotes microbial growth and increase their metabolism in the feed. Al-Thubiani and Khan (2017) has revealed the potential of extracted dietary fiber concentrate from date seeds as prebiotic by promoting the growth of *Lactobacillus paracasei spp paracasei* in low pH medium. These probiotic bacteria can be effectively improve fish gastrointestinal tract by balancing the microflora community in fish intestine (Al-Thubiani and Khan, 2017; Azizi et al., 2021). However, little is known on the effect of PDM on bacteria diversity in fish intestinal due to limited amount of research that had focused on this subject matter. In broiler, 10 % of degraded date pits (DDP) diet had revealed significant results in reducing the population of pathogenic bacteria in gut such as Salmonella spp., Campylobacter spp., Shigella spp. and *Escherichia coli* (Alyileili et al., 2020). In line with the findings, recent study also reported a reduction on intestinal bacteria count of similar genus in *Liza ramada* fingerling when fed with fermented date pits diet as compared to control fish (Moustafa et al., 2020). Overall, the enhanced compositions of amino acids, fatty acids and minerals in fermented PDM could provide positive impacts on intestinal microbial activity that may enhance the fish resistance to pathogenic bacteria in their intestine. Furthermore, PDM could also increase fish digestibility of nutrients in the gut, thus resulted to high efficiency of feed and protein uptake by the fish (Dawood et al., 2020a).

9. The effect of PDM on the blood related indices

Generally, one of the indicators of the physiological condition of fish is measured by changes in the blood indices. There are many studies on the effects of nutrition on animals which used haematological, biochemical, and physiological markers as indicators of health and growth performance (Burgos-Aceves et al., 2019; Dawood et al., 2020a; Faggio, 2014; Zulhisyam Abdul et al., 2020a). Fish blood haematological and biochemical parameters could be influenced by several factors such as species, sex, stress, environmental conditions and physiological nutritional status (Najim et al., 2014). Haematological variations have been detected in fish that were fed PDM as a major protein source. Uczay et al. (2019) suggested that adding protein from vegetables or plant meal in the feed damages the blood parameters. In contrast, the study by Dawood et al. (2020b) indicated that the inclusion of PDM improved haematological parameters compared with the control and others treatment of Nile tilapia. In their study, they used the fermented date seed meal and assumed that the dietary can positively ameliorate most of the blood indices in fish as a result of improve immunity. In addition, the fermented date seed meal also improves the immune function in fish body by activating the immunity of intestinal barriers. According to Mohammadi et al. (2018) showed that higher values in erythrocytic indices (i.e. RBC, PCV, Hb, MCHC, MCH and MCV) in fish fed with 0.5 % date palm seed compared to higher dosages may be in part due to the positive effect at a lower concentration of the phenolic and flavonoid substances provided in date pal seed. In their study, the improvement in fish growth and health performances occurred only at a low dosage of 0.5 % date palm seed in fish feed. The others study by Najim et al. (2014) used the fish biosilage which is the combination of fermenting marine by-catch fish with date fruit residues, domestic vinegar and citric acid fed the *Cyprinus carpio* fingerlings showed the improvement in haematological parameters (RBC, WBC, Hb and Hct) after 14 weeks feeding trial.

The works by Sotolu et al. (2014) indicated that the haematology of fish was generally better from diets in all date palm seed fed fish and supplementation of date palm seed at 1.5 % level as feed additive is recommended in catfish feeding for improved fish performance. In their study, there were non-significant difference the blood parameters assessed (PCV, Hb, Rbc and Wbc) and it could serve as indication that it can be included in fish diet to prevent anaemic condition. This observation is similar to the reports of Al-Maiman (2005) that observed favourable effects of fibers of date palm seed (*Phoenix dactylifera*) on plasma lipids in rats and Harikrishnan et al. (2003) on *Cyprinus carpio*, following herbal treatment. In the study by Mousallamy and Samir (2009) it was further ascertained that use of plant-based feed additive (fenugreek seed meal) is capable of improving blood parameters which is attributed to a shift of water from the plasma to the muscle cells, thereby increasing the haematocrit concentration. In contrast, the study by Kamali-Sanzighi et al. (2019) indicated that there were no significant differences of Hct, MCV, MCH and all biochemical parameters between treatment groups but improvement were occurred in the growth and feed utilisation parameters with the 10 % of waste date inclusion to the diet. In their study, the partial replacement of waste date was tested in the diet of fingerling Common carp. So, from the information above, it is proven that blood biochemical parameters can be improved by the PDM and the percentage of inclusion needs to be identified for better growth and health performances in fish.

10. The effect of PDM on the immune response

The use of probiotics, prebiotics, and herbal immunostimulants to modify the immunological response of fish has piqued interest in recent decades (De et al., 2014; Pohlenz and Gatlin III, 2014; Song et al., 2014).

It was reported that date palm fruit bioactive compounds show potent antioxidant, anticancer, antimutagenic, antibacterial, anti-inflammatory, and anti neurodege nerative capabilities in vitro and in vivo (Chaira et al., 2009; Vayalil, 2012) albeit these actions have not been established in fish. An overview of the PDM feeding on immune parameters in different fish species is presented in Table 6. The results obtained by Hoseinifar et al. (2015) showed that mucosal immune markers such as total immunoglobulin (Ig), lysozyme, protease, and ALP activity were enhanced in fry common carp (*Cyprinus carpio*) fed a date palm fruit extract (DPFE) diet. Although there is no report on the effect of dietary DPFE on fish immunological response, Karasawa et al. (2011) observed that a hot water extract from matured fruit of the date palm tree (*P. dactylifera L.*) stimulates the cellular immune system in mice, which is similar to the results of the previous study (Hoseinifar et al., 2015). In addition, a study on Artemia found that using DPFE significantly improved culture conditions while also suppressing bacterial infections in vivo (Mahdhi et al., 2013).

Date seed meal (DSM)-integrated meals have been shown to improve growth performance, immunological response, oxidative state, and stress resistance in aquatic animals in previous research (Ahmed et al., 2017; Akbarzadeh et al., 2019; Kamali-Sanzighi et al., 2019). Dawood et al. (2020a) reported that haematological counts of haemaglobin, red blood cells and white were improved in Nile tilapia (*Oreochromis niloticus*) fed the fermented DSM with *Aspergillus oryzae* when compared to the control and other groups. It has been assumed that dietary fermented DSM can improve most of the blood indices in tilapia fish which could lead to the enhanced immunity. By activating the immunity of intestinal walls, the presence of fermented DSM contributed to increase immunological function in fish blood. In addition, the same study (Dawood et al. (2020a) also reported that serum lysozyme activity increased considerably in fermented DSM-fed groups.

The quantity of immune system cells such as monocytes, macrophages, and polymorphonucleated granulocytes, which are the main source for such proteolytic enzymes, has been linked to an increase in lysozyme activity in fish, according to Saurabh and Sahoo (2008). Furthermore, higher lysozyme activity in the blood of stimulated fish was linked to either proliferating phagocytes or greater levels of lysozymes produced by lysosomes, making lysozyme activity one of the finest markers for evaluating the bactericidal effect of the diet nutritional value. Guardiola et al. (2016) showed that the total IgM levels, protease, and peroxidase activities in the serum did not change significantly following the dietary supplementation of DPFE alone or in combination with probiotics in European sea bass (*Dicentrarchus labrax*), while the anti-protease and haemolytic complement activity in the serum did. The activity of proteases used by certain bacteria to invade the host is inhibited by antiprotease activity in serum (Akhter et al., 2015). In term of humoral innate immune system, anti-protease, protease, lysozymes, antibodies, complement factors, bactericidal components, and other lytic factors, are the peptides present in serum, where they limit adhesion and colonisation of microorganisms (Alexander and Ingram, 1992), resulting in infection and illness prevention (Kaleeswaran et al., 2010). Furthermore, trypsin inhibitory action has been shown to modulate protein hydrolysis in vivo, which enhances pathogen defence (Tremacoldi and Pascholati, 2002).

It was shown that, the combination of DPFE with the probiotic had a synergistic effect on the phagocytic cells of European sea bass (Guardiola et al., 2016). Moreover, the phagocytic ability and capacity of HK leucocytes was also increased in fish fed a mixed diet of DPFE. This finding indicates that date palm fruit extract can be utilised as an alternative to other compounds used to control aquaculture diseases (such as antibiotics or pesticides) (Ramasamy Harikrishnan et al., 2011). Furthermore, this natural immunostimulant is more environmentally friendly than manufactured compounds since it is more biodegradable and does not cause medication resistance (Logambal et al., 2000; Olusola et al., 2013).

11. The antioxidative capacity of PDM

Date palm tree has different plant parts such as leaves bark, pits, fruits and pollen shave. These parts of the date palm, as reported by Allaith (2008) and Yeh et al. (2009), contain high antioxidant including phytochemical compounds like phenolic acids, sterols, carotenoids, flavonoids and anthocyanins, compounds which demonstrates its huge potential as a natural immunostimulant. Backing up the above statement, Habib et al. (2014) and Mistrello et al. (2014) reported that the date seed, a major date fruit by-product (10 % of fruit), contains phenolic and flavonoid substances which contain antioxidants. Due to the presence of lignin and tannins in PDM, it has excellent antioxidant and antimicrobial activities Shafiei et al. (2010) as shows in Table 7.

The content of these constituents is said to vary with the date pit variety, picking stage, soil condition and location (Allaith, 2008). He also reported that the Al Sagey cultivar possessed the highest antioxidant and phenolic content. For the Tamr stage in two varieties of date

Table 7
Antioxidant capacity of six date cultivars at the *Blah* and *Tamr* stages.

Cultivar	Antioxidant activity (μmol TEAC/100 g DM)	
	Blah (khalal)	Tamr
Ahmar dli	108.40	98.90
Ahmar denga	99.10	98.70
Bou seker	129.30	78.70
Tenterguel	90.50	75.60
Lemdina	103.40	95.80
Tijib	114.30	99.30
Average	107.50	91.20

TEAC, trolox equivalent antioxidant capacity.
Source:Source: Mohamed Lemine et al. (2014).

Table 6
Effect of PDM feeding on immune parameters.

Species	Inclusion levels of PDM	Immune parameters	Findings/Relative change (%) compared to control diet (non-PDM diet)	References
European sea bass	Palm date diet (100 gkg-1)	Protease and anti-protease activities	No change	Guardiola et al. (2016)
		Immunoglobulin M	No change	
		Haemolytic complement activity	+94	
		Phagocytic activity	+26	
Common carp (Cyprinus carpio) fingerlings	4 % of date palm seed extract	Lysozyme activity	No change	Mohammadi et al. (2018)
		Chemiluminescent response	+100	
Common carp (Cyprinus carpio)	Date palm fruit extract at 200 ml kg-1	Skin mucus total immunoglobulin	+73	Hoseinifar et al. (2015)
		Skin mucus lysozyme activity	+57	
		Skin mucus protease activity	+57	
		Skin mucus alkaline phosphatase activity	+66	

palm fruit (Deglet Nour and Khouet Kenta), antioxidant content values were on the range of 866.82–1148 μmol trolox equivalents/100 g fresh weight, as reported by Saafi et al. (2009). The antioxidant properties in PMD were confirmed by the presence of these phenolic compounds in their composition Maqsood et al. (2020). The antioxidant compound content; phenols, tannins, and vitamin C; had a negative correlation with fruit maturation while a positive correlation occurred between the antioxidant capacity and the antioxidant compound content. The evidence of antioxidant content in date palm has been proved by many researchers (Al-Turki et al., 2010; Amorós et al., 2009). Due to belief in its medicinal properties, it is used for potential health benefits (Allaith, 2008). PDM contain selenium, an antioxidant that can help the body cleanse and keep the organs in a good condition (Klein and Kiat, 2015). It has been discovered that carotenoids are a significant component of the phytochemicals found in the lipid parts of PDM (Al-Alawi et al., 2017). These contain vitamin A precursors, that play an important role in vision and protect cells from the damaging effects of reactive radicals by functioning as antioxidants. Vitamin A is essential for healthy eyesight (Idowu et al., 2020). In addition, flavonoids are a significant component of polyphenolic compounds derived from plants including PDM, and they can aid in the prevention of chronic illnesses and cardiovascular disorders (Machha and Mustafa, 2005).

A huge number of research studies on the advantages of date palm fruits have been made; several authors reported that there was significant antioxidant activity in PDM, this claimed by Awad et al. (2011) and Hammouda et al. (2013). To put weight on the statement, it is also a well-known fact to specialists that date palm can be used for the management of oxidative stress-related and infectious diseases. With the goodness of date palm proved in the above statements, it can be concluded that the inclusion of by-products obtained from date palm in fish diet can be a potential feed ingredient, with its antioxidant qualities also kept in mind. Since the health of fish can be augmented through the inclusion of date palm meal in its diet, it is a potential and very promising method of controlling diseases and stressors. To elaborate further on its ability to benefit health, in previous studies, it was proved through experimentation that date palm extracts improve mucosal immunity and gene expression, hence proving that date palm fruit can act as well-working natural antioxidants (Cerezuela et al., 2016; Esteban et al., 2014). To conclude here, regarding the growing interest in natural antioxidants, especially of those with plant source, to replace synthetic antioxidants because of their potential better health benefits compared to the former, date palm by-products should be taken into serious consideration (Najafian and Babji, 2012; Sarmadi and Ismail, 2010). In spite of this, there are a number of factors that contribute to the lowering of the actioxidant activity of PDM. The storage at room temperature resulted in a decrease in overall antioxidant activity in dates, which may have been caused by the transformation of soluble tannins into insoluble tannins or the enzymatic degradation and depletion of flavanoids and caffeoyl shikimic acid, among other factors (Ghnimi et al., 2017).

12. Potential new product development (NPD) of palm dates in aquaculture industry

Nowadays, a good and quality research will come out with end-product which is very useful to community and economic impact. In the aquaculture industry, the product produced can be any form and used different technology to apply in the actual aquaculture activity at commercial stage. The recent study by Zulhisyam et al. (2020b).

suggested that coating technique can be applied to aqua feed and resulted in better growth and health performances of *Claris gariepinus* species. Although the product is not from palm dates but the new product development process that were underwent throughout for establishing the product from their research can be a good example of how this product was developed by following the eight major steps in the new product development process. The discussion in the sub-chapter above proved that palm dates are rich with nutrition that suitable and beneficial for fish. Moreover, these benefits open up to a broader exploration for a new product development from palm dates for the aquaculture industries (Shahidi, 2005). It is of crucial importance to understand consumers, markets, and competitors in order to develop products that deliver superior value to customers (Schilling and Hill, 1998). In other words, there is no way around a systematic, customer-driven new product development (NPD) process for finding and growing new products (Tzokas et al., 2004). Further analyze the new product development of palm dates in aquaculture industries, we are in need to follow eight major steps in the new product development process. Starting from idea generation, typically, a company generates hundreds of ideas, maybe even thousands via sketching individually and in teams (Nik Ahmad Ariff and Badke-Schaub, 2011; Nik Ahmad Ariff et al., 2012) and proceed the ideas for prototyping and production, to find a handful of good ones in the end. Next, Idea screening, Concept development and Testing, Marketing strategy development, Business analysis, Product development, Test marketing, and finally commercialisation. In conclusion, based on the evidence are found in the previous literatures proved that PDM has a big potential in producing a quality product for aquaculture industry since it is also a sustainable source used for fish feed.

13. Conclusion

PDM can enhance the growth and health performances of aquatic species. Although the nutrient content may be at limited availability to aquatic species owning to its high fiber content, it can be improved via various technologies including solid-state fermentation (SSF). Furthermore, PDM also contains various bioactive compounds which may benefits the animal's health and well-being. This may subsequently replace the antibiotic application in aquaculture industry. In conclusion, the application of protein replacement or supplement from PDM in fish feed has a bright potential to obtain a good quality of fish feed and put this industry at a high level.

Funding

The APC was funded by INTI International University.

Author contributions

All authors shared equally in this work. All authors have read and agreed to the published version of the manuscript.

CRediT authorship contribution statement

Zulhisyam Abdul Kari: Writing – review & editing, Project administration. **Khang Wen Goh:** Writing-review, Writing – original draft. **Hisham Atan Edinur:** Writing – review & editing. **Khairiyah Mat:** Writing – review & editing. **Hazreen Nita Mohd Khalid:** Writing – review & editing. **Nor Dini Rusli:** Writing – review & editing. **Suniza Anis Mohamad Sukri:** Writing – review & editing. **Hasnita Che Harun:** Writing – review & editing. **Lee Seong Wei:** Writing – review & editing. **Muhamad Hakim Bin Mohd Ali Hanafiah:** Writing – review & editing. **Mohammad Mijanur Rahman:** Writing – review & editing. **Mohammad Khairul Azhar Abdul Razab:** Writing – review & editing. **Wendy Wee:** Writing – review & editing. **Nik Shahman Nik Ahmad Ariff:** Writing – review & editing. **Mahmoud A.O. Dawood:** Writing-review, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

We would like to thank Dr Nik Shahman bin Nik Ahmad Ariff from the Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur for his tremendous contribution in the New Product Development section of this paper. The shared knowledge in the topic is highly appreciated and successfully contributed to the new knowledge in this field. This study was funded by the Rising Star Grant Scheme (Grant No.: R/STA/A0700/00130A/003/2021/00933) and UMK Society Impact Research Grant Scheme (Grant No.: R/SIR/A0700/01083A/003/2020/00768) from Universiti Malaysia Kelantan, Malaysia. The APC was supported by INTI International University, 71800 Nilai, Malaysia.

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