EFFECTS OF MOISTURE CONTENT ON THE BAMBOO BORER *DINODERUS MINUTUS*

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Received November 2013

NORHISHAM AR, FAIZAH A & ZAIDON A. 2015. Effects of moisture content on the bamboo borer *Dinoderus minutus*. Infestation by the bamboo borer *Dinoderus minutus* (Coleoptera: Bostrychidae) on felled bamboo culms and products is a serious problem in the bamboo industry. However, biological studies on *Dinoderus* species are scarce. This study examined the development and reproductive aspects of the bamboo borer. Boring behaviour and biology of *D. minutus* at different moisture contents of *Gigantochloa scortechinii* were observed at 25 ± 3 °C under 8 hours light–16 hours dark regime. *Dinoderus minutus* showed significant differences in boring capacity and lifespan of adult beetles at different moisture contents. Infestation occurred as early as felling of bamboo and became severe as moisture content decreased to 15%. Female beetles deposited eggs individually into the metaxylem and incubation period varied from 4 to 6 days. Larvae fed along the metaxylem, leaving behind tightly packed frass. The overall life cycle of *D. minutus* in bamboo was 98.28 ± 1.26 days.

Keywords: Powder-post beetle, *Gigantochloa scortechinii*, life cycle, infestation, reproductive biology, life span

INTRODUCTION

Dinoderus minutus (Coleoptera: Bostrychidae) is an important borer that attacks felled bamboo culms and finished bamboo products to utilise stored starch (Beeson & Bathia 1937, Sulthoni 1988, Abood 2008). *Dinoderus minutus* thrives in relatively low moisture conditions (Fisher 1952, Gerberg 1957, Ivie 2002) and attacks seasoned bamboo and its products. Infestation by *D. minutus* covers a wide range of bamboo species such as *Bambusa bambos, B. polymorpha, B. textilis, B. vulgaris, Dendrocalamus giganteus, D. hamiltonii, D. strictus, Phyllostachys pervariabilis* and *P. pubescens* (Wang et al. 1998). Adult beetles burrow into culms through wounds, cracks and cut ends, making horizontal tunnels along the fibrovascular tissue, while the larvae make longitudinal tunnels. The faeces or frass is floury but of coarser nature than those of other powder-post beetles. In storage yards, stacks with immature culms become the starting point of attack and the bamboo is often converted to dust. About 40% of the bamboo stack may be lost within a period of 8 to 10 months (Thapa et al. 1992). Beetle infestation in storage yards was found to be highly unpredictable and borer incidence was apparently not related to season but on the quality of bamboo (Nair et al. 1983). Even when damage was slight, the presence of bore holes rendered the material unacceptable aesthetically, thus, resulting in economic loss (Abood 2008).

Bamboo susceptibility towards biodegradation agents, particularly *D. minutus,* is mainly associated with the availability of carbohydrate content (starch and sugar) and physical properties (moisture content and density) of the bamboo (Ho 1994, Garcia & Morrell 2008). A number of researchers have qualitatively observed a correlation between starch content and bamboo susceptibility (Plank & Hageman 1951, Mathur 1958). However, Dhamodaran et al. (1986) observed that the number of progeny produced by *D. minutus* on dried culms of bamboo reed did not correlate with starch content. In this study, the effects of moisture content on adult beetle boring capacity and lifespan were assessed. Adult beetles of *D. minutus* infesting *Gigantocholoa scortechinii* were collected from

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infested bamboo and transported back to the laboratory. The objectives were to study effects of different moisture contents on (1) the boring capacity and adult lifespan as well as (2) insect life cycle on bamboo.

MATERIALS AND METHODS

Insect

Adult *D. minutus* were collected from infested bamboo culms at the Bamboo Incubation Centre and Handicraft in Simpang Pertang, Negeri Sembilan, Malaysia (2° 57' N, 102° 18' E). Twenty severely-infected bamboo culms were collected for culture. Most bamboo culms infested by *D. minutus* were from *G. scortechinii*, which is an important species of bamboo in Malaysia (Wang et al. 1998). Infested bamboo culms were kept in a plastic container with dimensions of 30 cm × 20 cm × 25 cm, placed in a room at 75% relative humidity (RH) and 25 ± 3 °C with 8 hours light (L)–16 hours dark (D) regime. Newly-emerged beetles were collected and introduced into culture jars with bamboo to determine the age structure of the culture.

Preparation of bamboo

Boring behaviour and adult lifespan of *D. minutus* on bamboo blocks were tested at 89, 60, 30, 15 and 12% moisture contents. *Gigantochloa scortechinii* between 1 and 3 years old was extracted from the bamboo stand at Universiti Putra Malaysia. Selection of bamboo age was based on Aminuddin and Abd Latif (1991). They found that bamboos of 1 to 3 years old were more susceptible to powder-post beetle due to the availability of starch. Bamboo culms were cut into 1.0 to 1.5 m lengths and split into strips. Bamboo splits were cut into blocks (40 mm × 30 mm × original thickness) and grouped according to culms. Moisture content of bamboo blocks was determined based on Baronas et al. (2001).

Boring behaviour and lifespan

Newly-emerged *D. minutus* less than 1 day old were selected from the culture. Five bamboo blocks, each with different moisture contents, were placed in jars lined with filter paper. Each bamboo block was marked to distinguish the different moisture contents. Twenty newly-emerged beetles were introduced into each jar and kept for 24 hours to observe their boring behaviour. After 24 hours, bamboo blocks were taken out and kept in desiccators at humidity conditions designed to produce certain moisture content. Distilled water and saturated solutions of potassium acetate, sodium iodide, sodium bromide, sodium chloride and potassium chloride were used to maintain the required relative humidities for the bamboo blocks (Table 1).

Specific humidity levels were adjusted as described by Winston and Bates (1960) and measured using digital thermohygrometer. Adult lifespan was observed daily.

Cultures

Cultures of *D. minutus* were established on bamboo block set at optimum moisture content based on the longest lifespan and highest infestation. Ten replicates were established which consisted of five bamboo blocks placed inside a jar lined with filter paper. Twenty newly-emerged beetles were introduced into each jar. Sex of adults was determined based on Abood et al. (2010). The jars were kept at 75% RH and 25 ± 3 °C with 8L–16D regime. Ovipositional

Table 1 Salts used to maintain different levels of relative humidities

Humidity level (%)	Salt	Quantity (g 100 ml^{-1} H_2O)
20	Potassium acetae	200.0
40	Sodium iodide	184.0
56	Sodium bromide	116.0
75	Sodium chloride	36.0
85	Potassium chloride	28.1

behaviour and development from egg to adult were observed daily between 3 p.m. and 7 p.m. Inspections of larvae were carried out by gently slicing the uppermost layer of blocks with dissection knife under stereomicroscope.

Statistical analyses

The study was conducted in completely randomised design with five replications for each moisture content. Twenty adult beetles were used in each replication. Boring preferences and adult lifespan under different moisture contents were tested using one way analysis of variance (ANOVA). Significant differences between means were tested using Fisher's least significant difference (LSD). Statistical Analysis Software (version 9.2) was used for analysis.

RESULTS AND DISCUSSION

Entrance holes and lifespan of adult beetle

Adult beetles were observed to bore into the bamboo blocks within 24 hours of exposure at all moisture contents. Table 2 shows significant moisture content effect on number of entrance holes ($F = 34.58$, df = 4, 20; $p < 0.0001$) and lifespan ($F = 65.80$, df = 4, 95; $p < 0.0001$) of adult beetles. However, there were no significant differences in the number of entrance holes between 12 and 60% or 12 and 89% moisture content (LSD, $p \geq 0.05$; CV = 24.49). Bamboo at the lowest and highest moisture contents had lower numbers of entrance holes compared with intermediate moisture contents. The highest mean numbers of entrance holes recorded were 7.4 ± 0.3 and 6.0 ± 0.3 at 15 and 30% moisture contents respectively. Number of entrance holes decreased at 60% moisture content with mean of 3.0 ± 0.2 and continued to decrease with increasing moisture content. The lowest mean number of entrance holes recorded was 1.4 ± 0.1 at 89% moisture content, followed by 12% moisture content with mean of 2.2 ± 0.2 entrance holes.

The results showed that adult beetles were able to bore under all moisture contents tested but had different total boring capacities. However, the results did not support the research by Singh (1974) who reported that bamboo with moisture contents of less than 18% was practically immune to borers. In this study, the highest boring capacity was recorded at 15% moisture content. Sitaraman (1950) recorded similar boring patterns for *D. ocellaris* beetle on bamboo. Gnawing marks made by female beetles at the radial section were found to be testing marks to determine starch content of bamboo as reported by Abood (2008) on *Minthea rugicollis*. No entrance tunnel was observed within the outer layer of bamboo blocks. The presence of a large number of vascular bundles increases the density of the outer layer rendering tunnelling more difficult (Parameswaran & Liese 1976).

Figure 1 shows the survival of adult beetles with respect to moisture content of bamboo. Longest lifespans recorded were 53 and 51 days at 15 and 30% moisture contents respectively, with no significant differences between the two (LSD, $p \geq 0.05$; CV = 20.68). Continuous mortality of adult beetle were recorded at 89, 60 and 12% moisture contents from the first week of exposure with longest adult beetle lifespan of 17, 31 and 28 days respectively. However, there was no significant difference at 12 and 60% moisture content (LSD, $p \geq 0.05$; CV = 20.68).

Table 2 Number of entrance holes and lifespan of adult beetles at different moisture contents

Moisture content (%)	No. of entrance holes (Mean ± SE)	Adult lifespan (Mean days ± SE)
12	2.2 ± 0.2 cd	21.46 ± 0.50 b
15	7.4 ± 0.3 a	43.22 ± 0.75 a
30	6.0 ± 0.3 b	40.90 ± 0.73 a
60	3.0 ± 0.2 c	18.93 ± 0.76 b
89	1.4 ± 0.1 d	11.57 ± 0.54 c

Means followed by the same letter in the same column are not significantly different ($p \geq 0.05$); n = 5; SE = standard error

Insect behaviour in bamboo

Behaviour of adult *D. minutus* was observed on bamboo blocks at 15% moisture content where the highest number of entrance holes and longest lifespan were recorded. Adult *D. minutus* were observed crawling and gnawing around bamboo blocks immediately after introduction. Entrance tunnels extended towards the centre between walls in the hollow culm, where fibrovascular bundles were widely spaced. Size of bore holes varied from 0.87 to 1.16 mm with mean of 1.01 ± 0.16 mm (Figure 2a). Most adult *D. minutus* entered bamboo blocks from the cross- and tangential sections. Observations from cross-sections showed that adult *D. minutus* bore longitudinally and moved transversely after a short distance from the entrance hole (Figure 2b). However, *D. minutus* was observed to bore longitudinally from the tangential section. Gnawing marks were made by female beetles on radial sections (Figure 2c). No entrance tunnels were observed within the outer layer of bamboo blocks. Mating was noted outside the bamboo block before boring. Copulation was observed within 24 hours after each pair was introduced to the bamboo block. The male was seen approaching the female from the back a few times (Figure 2d). Copulation was also noted during female boring. The female exposed her abdomen outside the tunnel and was approached by the male. The process of copulation was very short, being completed in about 10 s. Oviposition activity was recorded at 12, 15 and 30% moisture content. The eggs were mainly deposited individually in the metaxylem (Figure 2e). Single females were noted to deposit single eggs in different metaxylem. Earliest deposition of eggs was noticed on day 6 after exposure. Determination of number of eggs laid by female was not carried out as inspection using the razor blade by slicing each layer of bamboo block damaged most of the eggs. Most of the eggs were located in bamboo blocks at 15% moisture content. Inspection showed that adult *D. minutus* were capable of laying eggs with or without boring into bamboo blocks. Most eggs were located near the boring area. Deposition of eggs without boring by adult female was recorded in cracks and cut ends. The perpendicular distance between eggs and beetle boring tunnels was 1.39 ± 0.05 mm. This distance might reflect the maximum ovipositor length of female beetle.

Mating behaviour of *D. minutus* was noted by Cymorek (1968) on bostrychid beetle and reported in *D. ocellaris* by Aziz and Sitaraman (1948). Mating of adult beetles took place outside bamboo blocks before boring. This result differed from Ho (1994) who reported that *D. minutus* mating occurred inside the tunnel, after which, the female laid eggs in exposed vessels. Oviposition by female beetles was only recorded at 12, 15 and 30% moisture contents.

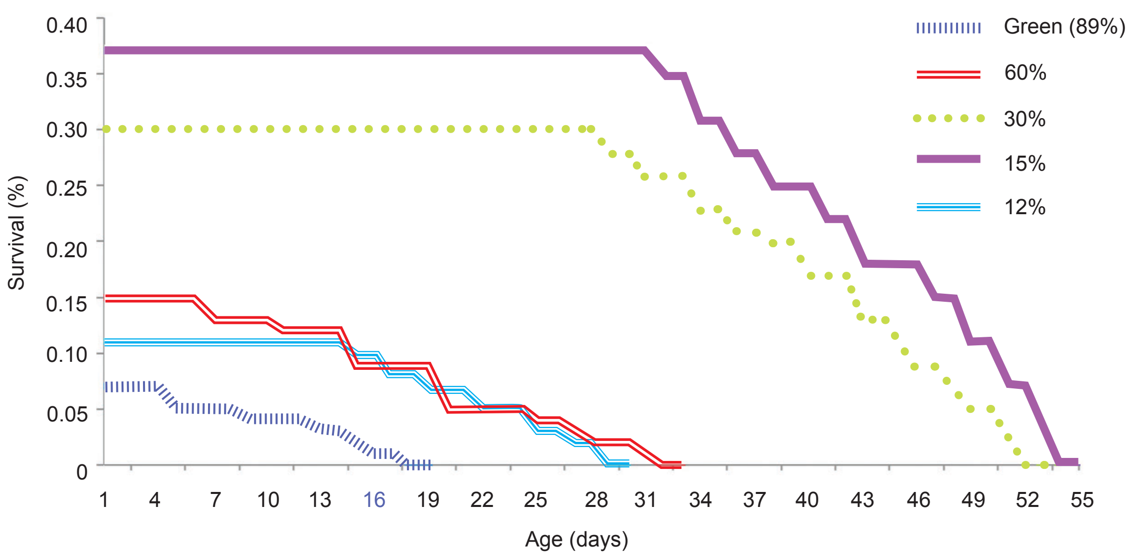

Figure 1 Percentage survival of adult beetle in bamboo of different moisture contents

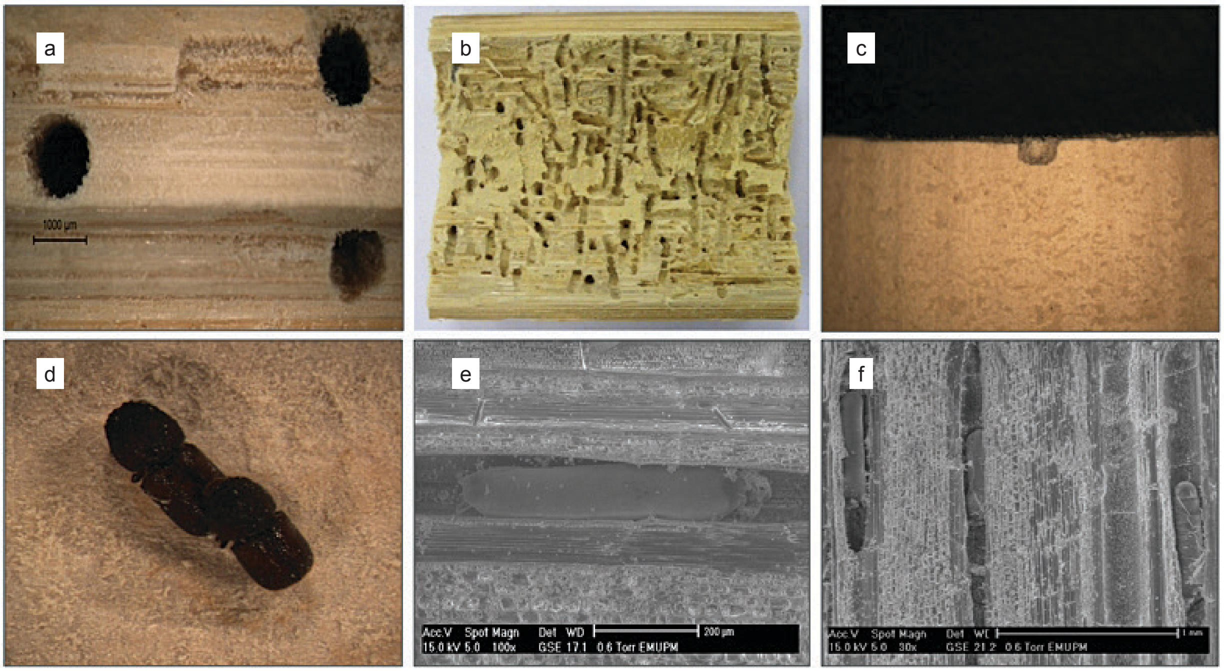

Figure 2 Boring pattern and ovipositional characteristics of *D. minutus* on bamboo: (a) entrance holes by adult beetle from tangential side, (b) boring tunnels by adult beetle and larva (c) mandibular groove made by female beetle (60×), (d) male approaching female during copulation (20×), and (e) and (f) scanning electron micrographs of egg deposition in bamboo

Eggs were mainly deposited individually in the metaxylem, in large conducting vessels with diameters ranging from 0.15 to 0.197 mm (Garcia & Morrell 2009). This was probably to provide adequate space and food for larval development. Garcia and Morrell (2009) explained that female oviposition was restricted to bamboo metaxylem due to narrow diameter in phloem and parenchyma tissues (0.01–0.04 mm).

Developmental stages of *D. minutus*

Table 3 shows the developmental period of the different life stages of *D. minutus* on bamboo at 15% moisture content. Incubation period varied from 4 to 6 days with mean of 4.9 ± 0.2 days. Mean durations for larval and pupal stages were 44.2 ± 0.3 and 4.3 ± 0.2 days respectively. Longest adult lifespan recorded was 56 days with mean of 44.88 ± 0.59 days.

The developmental stages of *D. minutus* in bamboo are shown in Figure 3. Eclosion to first instar larva was completed within 24 hours. The first instar larva broke through the broader end with the tip of its abdomen and gradually wriggled out by contraction of body muscles leaving the chorion completely cut open. Newly-hatched larvae appeared to be creamy white in colour, while the head was reddish brown with setae scattered at the end of abdomen and head. After eclosion, the first instar larva began burrowing along the metaxylem leaving tightly packed frass and faecal matter behind. The larva enlarged the tunnel as it grew into succeeding instars. After three weeks, the larva was observed burrowing downwards coaxially along fibre length. The maxillary and labial palpi became longer and the colour changed to dark brown. The legs became comparatively longer and setae became more apparent. The larva became pupa after 6 to 7 weeks. Last larval instar prepared a pupation chamber located near the bamboo surface before developing into pupa. This behaviour assisted emergence of newly-emerged beetles. The newly-developed pupa was creamy white in colour, resembling adult. The colour of pupa gradually changed into yellow and reddish brown as it developed into newly-emerged beetle. The development of pupa ranged from 4 to 5 days.

The larva of *D. minutus* developed into pupa at 15% moisture content. Larva mortality

Table 3 Developmental period for *Dinoderus minutus* at 15% moisture content

Stage	Period (days)		
	Mean ± SE	Minimum	Maximum
Egg	4.9 ± 0.2	4	6
Larva	44.2 ± 0.3	43	51
Pupae	4.3 ± 0.2	4	5
Overall adult lifespan	44.9 ± 0.6	34	56
Overall life cycle	98.3 ± 1.3	87	118

n = 20; SE = standard error

was caused by failure to utilise cellulose due to unfavourable moisture content in bamboo. Wood-boring insects require cellulose as a source of carbohydrate and must ingest relatively large quantities of wood in order to extract sufficient digestible substances for growth (Cymorek 1968). Fischer (1928) found that wood-boring insects at moisture content as high as 40% could attack timber and larvae could develop in wood with moisture contents varying from 10 to 28%. It is not known how moisture content affects the rate of development of larvae but it is reported that eggs can be laid and larvae can feed on comparatively moist wood surfaces. The overall life cycle of *D. minutus* recorded at 15% moisture content was 98.28 ± 1.26 days (Table 3). Results seemed to differ from that of Ho (1994) who reported a shorter duration of 4 weeks for larva and a longer duration of 8 days for pupa of *D. minutus* infesting *G. schortechinii*. The difference in duration was due to variation in environmental condition. Garcia and Morrell (2009) reported longer duration in pupa at lower temperatures and shorter duration in larva at higher temperature from 15 to 30 °C for *D. minutus*. Ho (1994) who exposed *G. schortechinii*

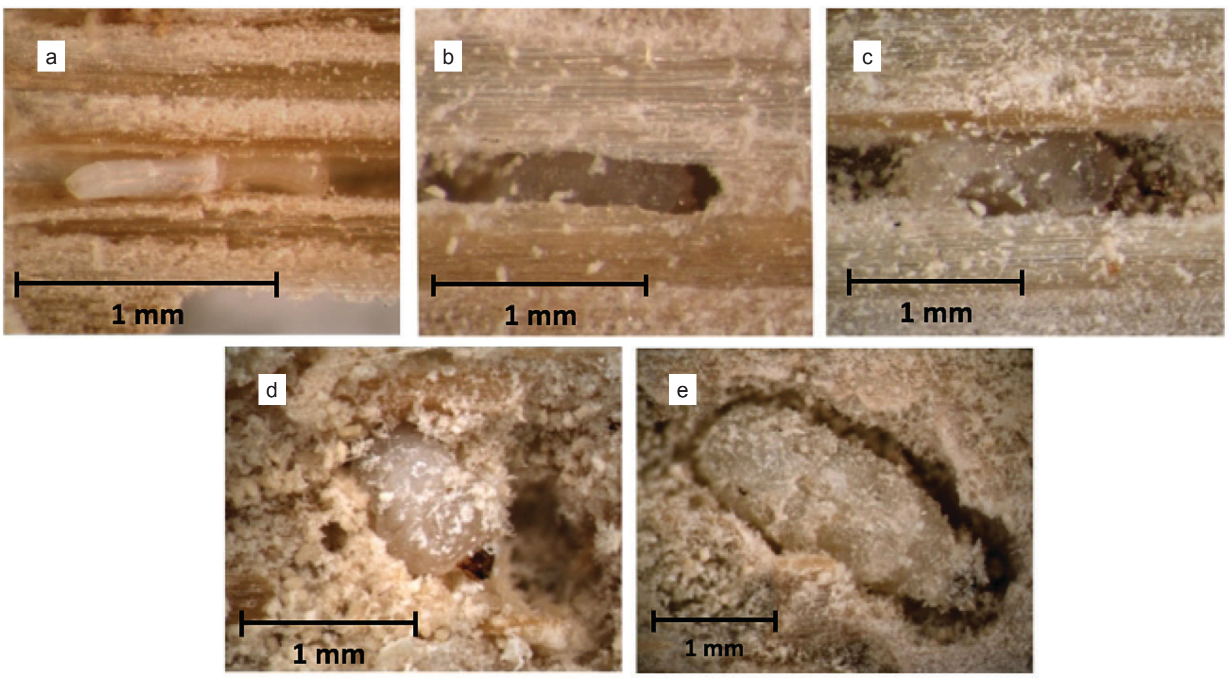

Figure 3 Developmental stages of *Dinoderus minutus* in bamboo: (a) eclosion to first instar, (b) 2-week-old larva, (c) 3-week-old larva, (d) 4-week-old larva and (e) pupa at 6 weeks

bamboo to different environmental conditions reported different durations for larva and pupa stages. We observed the last larval instar preparing a pupation chamber located near the bamboo surface before developing into a pupa. Garcia and Morrell (2009) noted this previously for *D. minutus* in *B. vulgaris*. Early felling of bamboo showed that the bamboo was susceptible to *D. minutus* as the number of entrance holes recorded was high at high moisture content and infestation became severe as moisture content decreased.

CONCLUSIONS

Dinoderus minutus completed its life cycle at 15% moisture content between 87 and 118 days with mean of 98.28 ± 1.26 days. Moisture content is an important factor that determines the rate of development of *D. minutus* in bamboo. Boring tunnels were reported at all moisture contents tested but results varied with different lifespan and ovipositional patterns. Oviposition was only recorded between 12 and 30% moisture contents. The highest number of eggs was in bamboo of 15% moisture content. They successfully hatched and developed into pupae at 15% moisture content. Adult lifespan was similar at 15 and 30% moisture contents but no larva developed into pupa at 30% moisture content.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the FRGS grant, the Ministry of Science Technology and Innovation Malaysia and Universiti Putra Malaysia for financial assistance and facilities.

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