

Antimicrobial properties of local Kelulut honey against selected oral pathogens

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Abstract

There are limited reports on the antimicrobial properties of Kelulut honey against oral pathogens. Hence, this study aimed to determine the antimicrobial properties of local Kelulut honeys obtained from the Malaysian Agriculture Research and Development Institute (MARDI) and Tangkak, Johor, Malaysia. The samples were mixed with sterile deionised water to obtain series of honey concentrations and evaluated against *Streptococcus mutans*, *Staphylococcus aureus*, *Candida albicans* and *Candida tropicalis* using agar well diffusion method. Bacteria *S. mutans* and *S. aureus* were grown anaerobically on Mueller-Hinton agar and incubated at 37°C for 24 hours, while fungi, *C. albicans* and *C. tropicalis* were grown on Sabouraud Dextrose agar at 25°C for 48 hours. Cultures were prepared in triplicates and adjusted to 0.5 McFarland standard (1 x 10⁸ CFU/ml). Wells (6 mm diameter) were made on the agar, and 60 µl of honey at concentrations of 2.5, 2.0, 1.5, 1.0 and 0.75 g/ml were added onto each well. Sterile deionised water was used as negative control, and 0.2% chlorhexidine as positive control. Upon incubation, the zones of inhibition were measured using a digital calliper. Both Kelulut honeys exhibited zones of inhibition against *S. mutans* at 2.5, 2.0 and 1.5 g/ml whereas for *S. aureus*, the inhibition was noticed only at 2.5 and 2.0 g/ml. No inhibition zones were observed against *C. albicans* and *C. tropicalis* at any concentration. This study showed that both Kelulut honeys exhibited antibacterial properties against *S. mutans* and *S. aureus* but did not exhibit antifungal activity against *C. albicans* and *C. tropicalis*.

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Introduction

In general, the oral cavity is colonized with diverse of oral microbiota, composed of more than 700 microbial species (Guo *et al.*, 2014). Nonetheless, some of these bacterial species, including *Streptococcus mutans* (*S. mutans*) and *Streptococcus sobrinus* (*S. sobrinus*) (Bloch *et al.*, 2024), have been reported to cause oral diseases such as carious lesions and periodontal diseases (Godocikova *et al.*, 2025). *Porphyromonas*

gingivalis (*P. gingivalis*) and *Fusobacterium nucleatum* have been indicated to be the main pathogens responsible for periodontal disease (Zhang *et al.*, 2022). Research have also shown that many oral microorganisms are also related to oral squamous cell carcinoma such as *P. gingivalis* (Wen *et al.*, 2020) and *Treponema denticola* (Fitzsimonds *et al.*, 2020). Not only bacteria, but also oral *Candida*, a type of opportunistic fungus potentially can cause oral infections, for instance denture stomatitis (Yusoff *et al.*, 2016).

In order to eradicate the manifestations of oral pathogens in the oral cavity, oral hygiene practices are undeniably required. Mechanical brushing, interdental cleaning (Mandal *et al.*, 2017), and antiseptic mouthwashes (Brookes *et al.*, 2023) were some of the oral hygiene practices represented. However, among those practices, a great concern has been focused on antiseptic mouthwashes, whereby their application can be both advantageous and deleterious (Brookes *et al.*, 2023). Additionally, some research has suggested that mouthwashes, such as chlorhexidine may increase the risk of fatality among critically ill patients (Bellissimo-Rodrigues *et al.*, 2019). To address safety concerns about long-term use of mouthwashes, natural products such as honey containing various antimicrobial factors should be introduced. A prior study by Deglovic *et al.* (2022) found that honey not only has antibacterial properties but also inhibits the cariogenic process.

Honey, a supersaturated sugar solution that comes from the nectar of flowers collected by the bees is referred as one of the natural products that has long been recognized to have antimicrobial properties (Ogwu & Izah, 2025). Honey has been exploited for its nutritional and therapeutic benefits for millennia and exhibit powerful antibacterial effects against a range of infections, including methicillin-resistant *S. aureus* (MRSA) and *Pseudomonas aeruginosa* (Mandal & Mandal, 2011).

Kelulut honey, a type of honey produced by stingless bees of *Trigona* species. It contains trehalulose, which is a rare and healthy sugar, an isomer of sucrose with an unusual α -(1 \rightarrow 1) glucose-fructose glycosidic linkage with known non-cariogenic and low glycaemic index properties (Fletcher *et al.*, 2020) and hence suitable for individuals with diabetes. It contains high amount of glucose, fructose, sucrose and maltose, as well as gluconic acid, malic acid and citric acid (Mato *et al.*, 2003; Haron *et al.*, 2022). In addition to trehalulose, Kelulut honey is also rich in bioactive compounds such as flavonoids, glucose oxidase catalase, and phenolic acids (Zulkhairi *et al.*, 2018) and

exhibits high antioxidant (Liu *et al.*, 2013; Ranneh *et al.*, 2018), antimicrobial (Kateel *et al.*, 2018) and wound healing properties (Adewumi & Ogunjinmi, 2011; Rashidi *et al.*, 2016). *In vitro* studies have also proven its substantial antimicrobial activity against *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Enterococcus faecalis*, *Escherichia coli*, *Salmonella typhimurium* and *P. aeruginosa* (Boorn *et al.*, 2010).

The antibacterial properties of honey are primarily attributed to its acidity (Almasaudi, 2021), osmotic effect (Molan, 1992), and the presence of peroxide and non-peroxide compounds (Almasaudi, 2021). Honey typically has a pH between 3.2 and 5.4, resulting from enzymatic activity that produces gluconic acid during nectar ripening (Molan, 1992). This acidic environment inhibits bacterial growth, as bacteria generally thrive at a pH of 7.2 to 7.4 (Almasaudi, 2021). The honey's osmotic effect, caused by strong interactions between sugar and water molecules, limits the availability of water for microbial growth (Mandal & Mandal, 2011). Additionally, peroxide compounds, like hydrogen peroxide (H₂O₂), increase oxidative stress, aiding in the regulation of bacterial colonization (Brudzynski *et al.*, 2011; Combarros-Fuertes *et al.*, 2020). Non-peroxide antimicrobial activity is mediated by a range of compounds, including phenolic compounds (Kwakman & Zaat, 2012), leptosperin (Roberts *et al.*, 2015), methylglyoxal (Girma *et al.*, 2019; Nader *et al.*, 2021), flavonoids, and antimicrobial peptides (Kwakman *et al.*, 2011).

Even though numerous research has shown the antimicrobial properties of other honeys, such as Manuka honey and Slovak honey against oral and non-oral pathogens (Godocikova *et al.*, 2025), there is still a lack of information regarding these powerful properties of local Kelulut honey against oral pathogens. Further, the urge to use natural products possessing antimicrobial properties, such as honey, is worth exploring, as it has fewer risks to human health. Hence, by exploring these properties, it has broadened and shed some light on the beneficial values of Kelulut honey as well as

added value for the honey to be commercialized and known in the future. Therefore, this study aims to determine the antimicrobial properties of local Kelulut honey against selected oral pathogens, namely, *S. mutans*, *S. aureus*, *Candida albicans* (*C. albicans*) and *Candida tropicalis* (*C. tropicalis*) using agar well diffusion method. Two local Malaysian Kelulut honeys obtained from the Malaysian Agricultural Research and Development Institute (MARDI) and Tangkak, Johor, Malaysia was evaluated for their antimicrobial properties in this study.

Materials and Methods

Preparation of honey samples

Both the honey samples were mixed with sterile deionised water to produce honey

solutions as described by Mohd-Aspar *et al.*, (2023). They assessed a few types of honey from concentrations 30% to 90% (w/v) and the samples were prepared by weighing 3, 4, 5, 6, 7, 8 and 9 g of honey and mixing with deionised water making a final volume of 10 ml. However, the concentrations of the honey in current study were slightly different from the previous study. The stock solution concentration of 2.5 g/ml for both honeys was prepared by mixing 7.5 g of undiluted honey with 3 ml of sterile deionised water (w/v). The subsequent concentrations prepared from the stock solution are presented in Table 1.

The pH of stock solutions of each honey sample was then measured using microprocessor pH meter (Hanna Instruments, USA).

Table 1. Preparation of different concentrations of honey samples.

Volume of honey stock (ml)	Volume of deionised water (ml)	Final volume (ml)	Concentration (g/ml) (w/v)
0.8	0.2	1.0	0.8 x 2.5 g/1 ml = 2.0 g/ml
0.6	0.4	1.0	0.6 x 2.5 g/1 ml = 1.5 g/ml
0.4	0.6	1.0	0.4 x 2.5 g/1 ml = 1.0 g/ml
0.3	0.7	1.0	0.3 x 2.5 g/1 ml = 0.75 g/ml

Microbial inoculum preparation

The microorganisms used in this study were *S. mutans* (ATCC 25175, USA), *S. aureus* (ATCC 33862, USA), *C. albicans* (ATCC 10231, USA), and *C. tropicalis* (ATCC 1369, USA). Bacteria, *S. mutans* and *S. aureus*, both facultative anaerobic bacteria were maintained in anaerobic conditions and the microorganism preparation method was adapted from a study by Mohd-Aspar *et al.*, (2023). Both the bacteria were cultured on Mueller-Hinton agar and incubated overnight at 37°C in a CO₂ incubator. Both fungi, *C. albicans* and *C. tropicalis* were

cultured on Sabouraud Dextrose agar and incubated at 25°C for 48 hours. Agar plates were prepared in triplicates for all microorganisms to ensure the growth of at least one microbial inoculum. Microbial inoculum preparations were done by suspending *S. mutans* and *S. aureus* in sterile Mueller-Hinton broth, while *C. albicans* and *C. tropicalis* were suspended in Sabouraud Dextrose broth and adjusted to a concentration equivalent to 0.5 McFarland standard (1 x 10⁸ CFU/ml).

Antimicrobial evaluation using agar well diffusion assay

Both Kelulut honeys were evaluated for their antimicrobial properties using the agar well diffusion assay as described by Yusoff *et al.*, (2016) with slight modifications. In brief, a sterile cotton swab was dipped into the inoculum suspension and evenly spread on Mueller-Hinton agar for *S. mutans* and *S. aureus*, and Sabouraud Dextrose agar for *C. albicans* and *C. tropicalis*. Following inoculation, wells 6 mm in diameter were created on the agar surface using the bottom of sterile 20 µl pipette tips. Then, 60 µl of both Kelulut honeys at concentrations of 2.5, 2.0, 1.5, 1.0 and 0.75 g/ml (w/v) were loaded onto each well. A 60 µl volume of sterile deionised water was used as a negative control, and 0.2% chlorhexidine as a positive control. This test was conducted in triplicates for each sample. The agar plate was then placed in an incubator for 24 hours at 37°C for bacteria, and 48 hours at 25°C for the fungus. The zones of inhibition were measured in millimetres using a digital calliper.

Results

The pH of Kelulut honey from MARDI was 2.51 ± 0.01 and that of Tangkak was 2.62 ± 0.01 . The zones of inhibition for the different microorganisms are presented in Table 2 and illustrated in Figures 1 and 2.

Discussion

The use and benefits of honey have been known since ancient times, largely due to its ability to prevent the growth of microorganisms in wounds (Kuropatnicki *et al.*, 2018). Honey is also recognized for its bacteriostatic and bactericidal effects against a wide range of microbes, including both Gram-positive and Gram-negative bacteria (Mandal & Mandal, 2011). However, only a few honey varieties, such as Capilano Medihoney, Active Manuka honey, and Revamil honey, have been approved for therapeutic use (Omar *et al.*, 2019). Recent studies have shown that honey from

stingless bees has antibacterial properties against a variety of pathogens, indicating its potential as an antibacterial agent (Irish *et al.*, 2008; Kimoto-Nira & Amano, 2008; Ewnetu *et al.*, 2013; Zainol *et al.*, 2013; Andualem, 2014; Eswaran *et al.*, 2015).

In this study, the antimicrobial properties of Kelulut honey evaluated using agar well diffusion assay showed varying effects against bacteria and fungi. Based on the results, both the Kelulut honeys showed zones of inhibition against *S. mutans* at 2.5, 2.0 and 1.5 g/ml. However, the zones of inhibition for *S. aureus* were noticed only at 2.5 and 2.0 g/ml (Table 2). The findings of this study differ from those of Mohd Izwan (2016) who demonstrated that 25% Kelulut honey could inhibit *S. aureus*. However, our results were in line with a study by Ahmadi-Motamayel *et al.* (2013) who reported that honey at concentrations above 20% was effective against *S. mutans*. Moreover, our results also in line with a study by Badawy *et al.* (2004) which reported that the concentrations of honey significantly affect its antibacterial activity, with higher concentrations generally showing greater effectiveness.

Most types of honey release H₂O₂ when diluted due to the activation of glucose oxidase, which oxidizes glucose to gluconic acid and H₂O₂, contributing to their antimicrobial properties (Bang *et al.*, 2003). In the current study, sterile deionised water was used as a honey diluent which facilitated the release of H₂O₂ (Kwakman & Zaat, 2012), potentially contributing to the observed zones of inhibition against both bacteria. The availability of water molecules from sterile deionised water was a vital component for the glucose oxidase-dependent catalysis (Brudzynski, 2020). Furthermore, the honey concentrations in this study, 2.5 to 0.75 g/ml (w/v) differed with the range of 30% to 50% (v/v) aqueous honey solution reported by Bang *et al.* (2003) where it was stated that this range was the optimal concentration for the highest buildup of H₂O₂.

Table 2. Antimicrobial effects of Kelulut honey from MARDI and Tangkak

Microorganisms	Zone of inhibition in mm (Mean ± SD)							
	<i>S. mutans</i>		<i>S. aureus</i>		<i>C. albicans</i>		<i>C. tropicalis</i>	
Samples	MARDI	Tangkak	MARDI	Tangkak	MARDI	Tangkak	MARDI	Tangkak
Negative control	-	-	-	-	-	-	-	-
Positive control	32.12 ± 0.12	33.37 ± 0.02	27.62 ± 0.07	27.31 ± 0.02	19.25 ± 0.36	20.43 ± 0.14	21.89 ± 0.24	22.72 ± 0.07
2.5 g/ml	15.26 ± 0.91	14.11 ± 0.09	10.48 ± 0.04	9.89 ± 0.1	-	-	-	-
2.0 g/ml	14.50 ± 0.17	9.91 ± 0.05	9.76 ± 0.05	8.73 ± 0.03	-	-	-	-
1.5 g/ml	13.68 ± 0.25	8.56 ± 0.04	-	-	-	-	-	-
1.0 g/ml	-	-	-	-	-	-	-	-
0.75 g/ml	-	-	-	-	-	-	-	-

Negative control = Sterile deionised water; Positive control = 0.2% chlorhexidine; '-' indicates no zone of inhibition

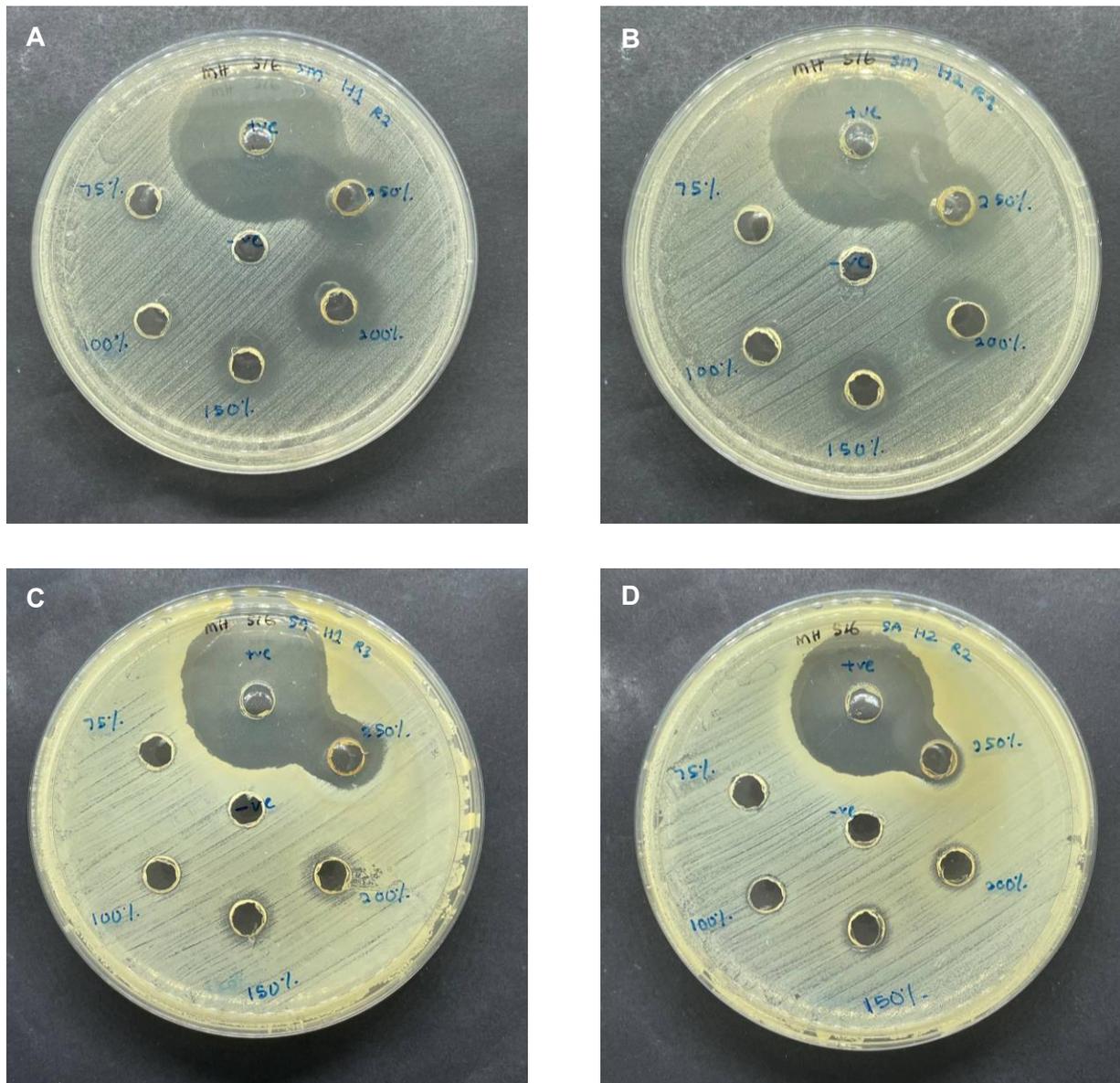


Figure 1. Zones of inhibition A. *S. mutans* (Kelulut honey from MARDI) B. *S. mutans* (Kelulut honey from Tangkak) C. *S. aureus* (Kelulut honey from MARDI) D. *S. aureus* (Kelulut honey from Tangkak).

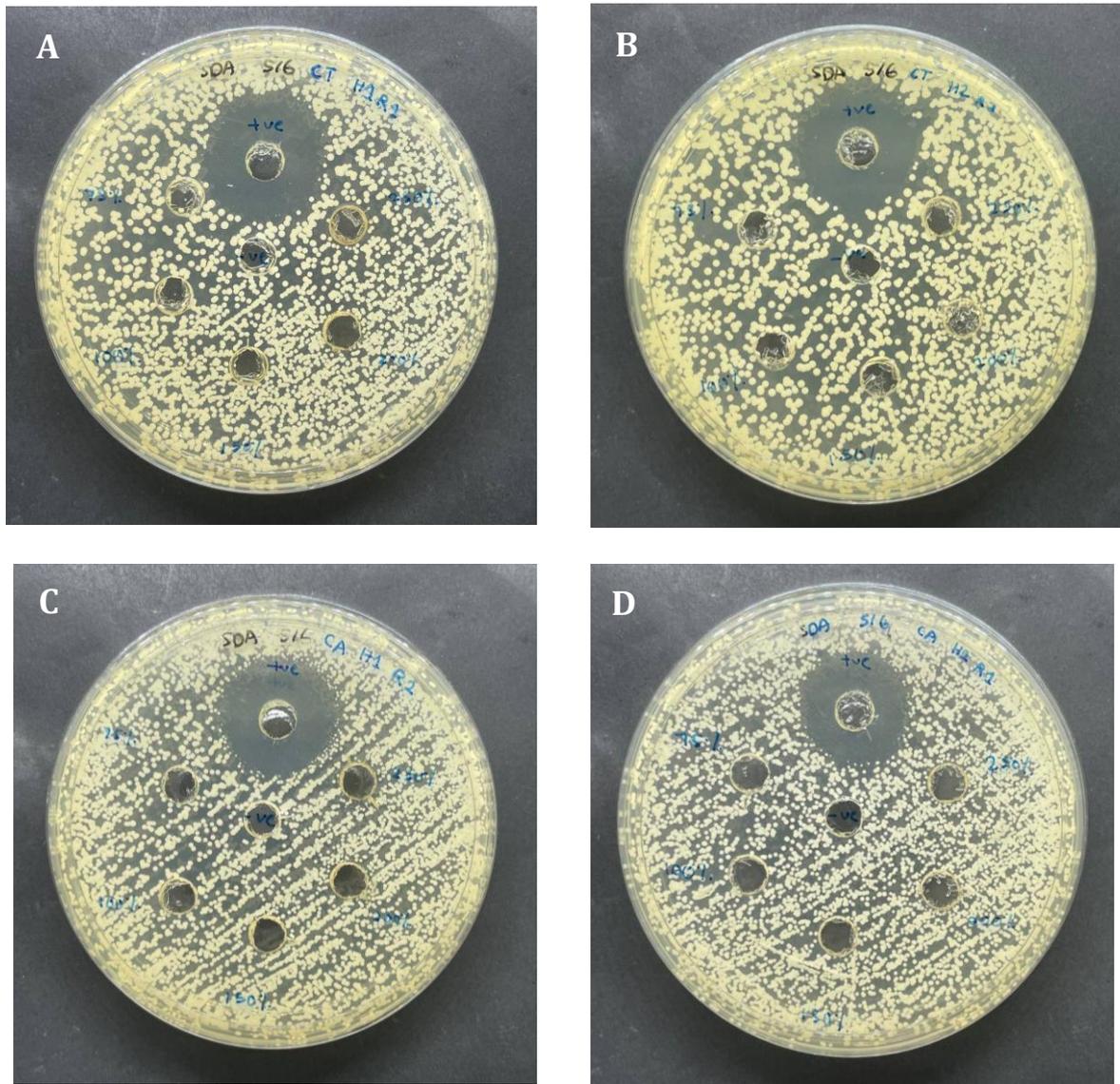


Figure 2. No zones of inhibition A. *C. tropicalis* (Kelulut Honey from MARDI) B. *C. tropicalis* (Kelulut Honey from Tangkak) C. *C. albicans* (Kelulut Honey from MARDI) and D. *C. albicans* (Kelulut Honey from Tangkak) except for the positive control (0.2% chlorhexidine)

Additionally, the antimicrobial potency of Kelulut honey in this study may also be linked to its acidic pH, recorded at 2.51 for Kelulut honey from MARDI and 2.62 for the sample from Tangkak, as well as the presence of polyphenolic compounds. The variations in pH values for both localities may be due to various factors including geographical area, nectar sources and environmental, as reported by Kaya & Yıldırım, (2021). In addition, common phenolic compounds in Kelulut honey include gallic acid, caffeic acid, catechin, apigenin, chrysin, kaempferol, *p*-coumaric acid and cinnamic acid. Among these, cinnamic acid is specifically noted for its antimicrobial properties in Kelulut honey (Zulkhairi *et al.*, 2018).

In the current study, Kelulut honey did not inhibit the growth of *C. albicans* and *C. tropicalis* at any of the tested concentrations. This contrasts with the findings of Yusoff *et al.* (2016), who reported that Kelulut honey exhibited antifungal activity against *C. albicans* and *C. tropicalis* in its pure form, although the activity was lost upon dilution (1:1 and 1:2 with distilled water). Our results are also in contrast with the findings of Zubaidah *et al.* (2018), where Kelulut honey at concentrations of 10%, 15%, and 25% was able to completely inhibit *C. albicans* and showed stronger antifungal activity compared to Tualang and Acacia honey.

The results of this research suggest that Kelulut honey samples (MARDI and Tangkak) demonstrate antibacterial properties but not antifungal activity. The differences in their effectiveness against different oral pathogens may closely related to the osmolarity factor of the honey. Bacteria were susceptible to the high osmolarity of honey (Jia *et al.*, 2020), while fungi were resistant to the honey's high osmolarity because of a particular high osmolarity glycerol (HOG) pathway (Hohmann, 2002). This pathway involves osmoadaptation of the yeast, a type of fungus, to adapt in high osmolarity conditions by sensing the osmotic changes and transmitting the signal to the transcriptional machinery for further

responses of the yeast cells. Hence, the resistance of both the fungi in the current study could be attributed to this HOG pathway. Furthermore, the antimicrobial potency of honey can vary significantly, often by more than 100-fold, depending on factors such as geographical, seasonal, and botanical origins, as well as the conditions under which the honey is harvested, processed, and stored (Molan & Cooper, 2000). Key contributors to its antimicrobial efficacy include osmolarity, H₂O₂ content, low pH, and the presence of phenolic acids and flavonoids (Almasaudi, 2021). Among these, H₂O₂ plays a dominant role, and variations in its concentration across different honeys result in differences in their antimicrobial effectiveness (Almasaudi, 2021). Thus, while Kelulut honey's antibacterial activity is evident, its antifungal potential may require further exploration under different conditions or concentrations of these active components.

Conclusion

In conclusion, this study demonstrates that Kelulut honey exhibits antimicrobial activities towards different oral pathogens. Kelulut honey possessed potent antibacterial properties, effectively inhibiting the growth of *S. mutans* and *S. aureus* at higher concentrations. However, it did not exhibit antifungal activity against *C. albicans* and *C. tropicalis*. From the results, it can be inferred that Kelulut honey selectively inhibits the growth of certain oral pathogens, which drives its efficacy only against those certain pathogens. Further research on Kelulut honey's antifungal efficacy against other oral fungi pathogens is required to validate the properties as well as to improve our medical and dental understanding.

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References

- Adewumi, A., Ogunjinmi, A. (2011). The healing potential of honey and propolis lotion on septic wounds. *Asian Pacific Journal of Tropical Biomedicine*, 1(1), S55-S57.
- Ahmadi-Motamayel, F., Sare Hendi, S., Alikhani, M., Khamverdi, Z., Khamverdi, Z. (2013). Antibacterial activity of honey on cariogenic bacteria. *Journal of Dentistry (Tehran)*, 10(1), 10-15.
- Almasaudi, S. (2021). The antibacterial activities of honey. *Saudi Journal of Biological Sciences*, 28(4), 2188-2196.
- Andualem, B. (2014). Physico-chemical, microbiological and antibacterial properties of *Apis mellipodae* and *Trigona spp.* honey against bacterial pathogens. *World Journal of Agricultural Sciences*, 10(3), 112-120.
- Badawy, O.F.H., Shafii, S.S.A., Tharwat, E.E., Kamal, AM. (2004). Antibacterial activity of bee honey and its therapeutic usefulness against *Escherichia coli* 0157:H7 and *Salmonella typhimurium* infection. *Revue scientifique et technique (International Office of Epizootics)*, 23(3), 1011-1022.
- Bang, L.M., Buntting, C., Molan, P. (2003). The effect of dilution on the rate of hydrogen peroxide production in honey and its implications for wound healing. *Journal of Alternative and Complementary Medicine*, 9(2), 267-273.
- Bellissimo-Rodrigues, W.T., Meneguetti, M.G., de Macedo, L.D., Basile-Filho, A., Martinez, R., Bellissimo-Rodrigues, F. (2019). Oral mucositis as a pathway for fatal outcome among critically ill patients exposed to chlorhexidine: Post hoc analysis of a randomized clinical trial. *Critical Care*, 23, 382.
- Bloch, S., Hager-Mair, F. F., Andrukhov, O., Schäffer, C. (2024). Oral streptococci: modulators of health and disease. *Frontiers in Cellular and Infection Microbiology*, 14:1357631.
- Boorn, K.L., Khor, Y.Y., Sweetman, E., Tan, F., Heard, T.A., Hammer, K.A. (2010). Antimicrobial activity of honey from the stingless bee *Trigona carbonaria* determined by agar diffusion, agar dilution, broth microdilution and time-kill methodology. *Journal of Applied Microbiology*, 108(5), 1534-1543.
- Brookes, Z., Teoh, L., Cieplik, F., Kumar, P. (2023). Mouthwash effects on the oral microbiome: Are they good, bad, or balanced?. *International Dental Journal*, 73 (Suppl 2): S74-S81.
- Brudzynski, K. (2020). A current perspective on hydrogen peroxide production in honey. A review. *Food Chemistry*, 332 (2020), 127229.
- Brudzynski, K., Abubaker, K., Laurent, M., Castle, A. (2011). Re-examining the role of hydrogen peroxide in bacteriostatic and bactericidal activities of honey. *Frontiers in Microbiology*, 25(2), 213.
- Combarros-Fuertes, P., Fresno, J.M., Estevinho, M.M., Sousa-Pimenta, M., Tornadajo, M.E., Estevinho, L.M. (2020). Honey: Another alternative in the fight against antibiotic-resistant bacteria? *Antibiotics*, 9(11), 774.
- Deglovic, J., Majtanova, N., Majtan, J. (2022). Antibacterial and antibiofilm effect of honey in the prevention of dental caries: A recent perspective. *Foods*, 11, 2670.
- Eswaran, V., Krishnadoss, V., Priya, V., Bhargava, H.R. (2015). A comparative study of the biochemical, antioxidative and antimicrobial activity of Apis and Trigona honey collected from different geographical areas of India. *World Applied Sciences Journal*, 33(1), 160-167.
- Ewnetu, Y., Lemma, W., Birhane, N. (2013). Antibacterial effects of *Apis mellifera* and stingless bees honeys on susceptible and resistant strains of *Escherichia coli*, *Staphylococcus aureus* and *Klebsiella pneumoniae* in Gondar, Northwest Ethiopia. *BMC Complementary and Alternative Medicine*, 13(1), 269.
- Fitzsimonds, Z.R., Rodriguez-Hernandez, C.J., Bagaitkar, J., Lamont, R.J. (2020). From beyond the pale to the pale riders: the emerging association of bacteria with oral cancer. *Journal of Dental Research*, 99: 604-612.
- Fletcher, M.T., Hungerford, N.L., Webber, D., De Jesus, M.C., Zhang, J., Stone, I.S.J., et al. (2020). Stingless bee honey, a novel source of trehalulose: a biologically active disaccharide with health benefits. *Scientific Reports*, 10(1), 12128.
- Girma, A., Seo, W., She, R.C. (2019). Antibacterial activity of varying UMF-graded Manuka honeys. *PLOS ONE*, 14(10), e0224495.
- Godocikova, J., Hrnčiarova, M., Deglovic, J., Bucekova, M., Majtan, J. (2025). Differences in the antibacterial efficacy of honey against oral and nonoral bacterial pathogens in artificial human saliva. *European Food Research and Technology*, 2025.
- Guo L, He X, Shi W. (2014). Intercellular communications in multispecies oral microbial communities. *Frontiers in Microbiology*, 5:328.
- Haron, H., Talib, R., Subramaniam, P., Natasha, Z., Arifen, Z., Ibrahim, M. (2022). A comparison of chemical compositions in kelulut honey from different regions (*perbandingan komposisi kimia dalam madu kelulut dari kawasan berbeza*). *Malaysian Journal of Analytical Sciences*, 26(3), 447-456.
- Hohmann, S. (2002). Osmotic stress signaling and osmoadaptation in yeasts. *Microbiology and Molecular Biology Reviews*, 66(2), 300-372.
- Irish, J., Carter, D.A., Blair, S.E., Heard, T.A. (2008). Antibacterial activity of honey from the Australian stingless bee *Trigona carbonaria*. *International Journal of Antimicrobial Agents*, 32(1), 89-90.
- Jia, L., Kosgey, J. C., Wang, J., Yang, J., Nyamao, R. M., Zhao, Y., et al. (2020). Antimicrobial and mechanism of antagonistic activity of *Bacillus*

- sp. A2 against pathogenic fungus and bacteria: The implication on honey's regulatory mechanism on host's microbiota. *Food Science & Nutrition*, 8(9), 4857-4867.
- Kateel, R., Bhat, G., Baliga, S., Augustine, A.J., Ullal, S., Adhikari, P. (2018). Antibacterial action of tropical honey on various bacteria obtained from diabetic foot ulcer. *Complementary Therapies in Clinical Practice*, 30, 29-32.
- Kaya, B., Yıldırım, A. (2021). Determination of the antioxidant, antimicrobial and anticancer properties of the honey phenolic extract of five different regions of Bingöl province. *Journal of Food Science and Technology*, 58(6), 2420-2430.
- Kimoto-Nira, H., Amano, K. (2008). Antimicrobial activity of honey produced by stingless honey bees. *Journal of Apicultural Research*, 47(4), 325-327.
- Kuropatnicki, A.K., Klósek, M., Kucharzewski, M. (2018). Honey as medicine: historical perspectives. *Journal of Apicultural Research*, 57(1), 113-118.
- Kwakman, P.H.S., te Velde, A.A., de Boer, L., Vandenbroucke-Grauls, C.M.J.E., Zaat, S.A.J. (2011). Two major medicinal honeys have different mechanisms of bactericidal activity. *PLOS ONE*, 6(3), e17709.
- Kwakman, P.H.S., Zaat, S.A.J. (2012). Antibacterial components of honey. *IUBMB Life*, 64(1), 48-55.
- Liu, J.R., Ye, Y.L., Lin, T.Y., Wang, Y.W., Peng, C.C. (2013). Effect of floral sources on the antioxidant, antimicrobial, and anti-inflammatory activities of honeys in Taiwan. *Food Chemistry*, 139(1-4), 938-943.
- Mandal, M.D., Mandal, S. (2011). Honey: Its medicinal property and antibacterial activity. *Asian Pacific Journal of Tropical Biomedicine*, 1(2), 154-160.
- Mandal, A., Singh, D.K., Siddiqui, H., Das, D., Dey, A.K. (2017). New dimensions in mechanical plaque control: An overview. *Indian Journal of Dental Sciences*, 9:133-139.
- Mato, I., Huidobro, J.F., Simal-Lozano, J., Sancho, M.T. (2003). Significance of nonaromatic organic acids in honey. *Journal of Food Protection*, 66(12):2371-2376.
- Mohd Izwan, Z. (2016). Study on antioxidant capacity, antibacterial activity, phenolic profile and microbial screening of selected Malaysian and Turkish honey: Thesis. University of Malaya, Kuala Lumpur.
- Mohd-Aspar, M.A.S., Edros, R., Mokhtar, S.U., Kamarudin, N. (2023). The roles of acidity, peroxide and non-peroxide compounds in antibacterial properties of Malaysian Kelulut, Tualang and Acacia honey. *Malaysian Journal of Microbiology*, 19(3), 291300.
- Molan, P.C., Cooper, R.A. (2000). Honey and sugar as a dressing for wounds and ulcers. *Tropical Doctor*, 30(4), 249-250.
- Molan, P.C. (1992). The antibacterial activity of honey. *Bee World*, 73(1), 5-28.
- Nader, R.A., Mackieh, R., Wehbe, R., El Obeid, D., Sabatier, J.M., Fajloun, Z. (2021). Beehive products as antibacterial agents: A review. *Antibiotics*, 10(6), 717.
- Ogwu, M.C., Izah, S.C. (2025). Honey as a natural antimicrobial. *Antibiotics*, 14(3), 255.
- Omar, S., Mat-Kamir, N.F., Sanny, M. (2019). Antibacterial activity of Malaysian produced stingless-bee honey on wound pathogens. *Journal of Sustainability Science and Management*, 14(3), 67-69.
- Ranneh, Y., Ali, F., Zarei, M., Akim, A.M., Hamid, H.A., Khazaai, H. (2018). Malaysian stingless bee and Tualang honeys: A comparative characterization of total antioxidant capacity and phenolic profile using liquid chromatography-mass spectrometry. *LWT*, 89, 1-9.
- Rashidi, M.K., Mirazi, N., Hosseini, A. (2016). Effect of topical mixture of honey, royal jelly and olive oil-propolis extract on skin wound healing in diabetic rats. *Wound Medicine*, 12, 6-9.
- Roberts, A.E.L., Brown, H.L., Jenkins, R.E. (2015). On the antibacterial effects of manuka honey: Mechanistic insights. *Research and Reports in Biology*, 6, 215-224.
- Wen, L., Mu, W., Lu, H., Wang, X., Fang, J., Jia, Y., Li, Q., Wang, D., Wen, S., Guo, J., Dai, W., Ren, X., Cui, J., Zeng, G., Gao, J., Wang, Z., Cheng, B. (2022). *Porphyromonas gingivalis* Promotes Oral Squamous Cell Carcinoma Progression in an Immune Microenvironment. *Journal of Dental Research*, 99(6): 666-675.
- Yusoff, N.Y.N., Mohamad, S., Abdullah, H., Rahman, N.A. (2016). Antifungal activity of Malaysian honey and propolis extracts against pathogens implicated in denture stomatitis. *AIP Conference Proceedings*, 1791(1), 020006.
- Zainol, M.I., Mohd Yusoff, K., Mohd Yusof, M.Y. (2013). Antibacterial activity of selected Malaysian honey. *BMC Complementary and Alternative Medicine*, 13(1), 129.
- Zhang, Z., Liu, S., Zhang, S., Li, Y., Shi, X., Liu, D., Pan, Y. (2022). *Porphyromonas gingivalis* outer membrane vesicles inhibit the invasion of *Fusobacterium nucleatum* into oral epithelial cells by downregulating FadA and FomA. *Journal of Periodontology*, 93(4), 515-525.
- Zubaidah, H., Irfan, M., Azian, H., Rosdan, S., Siti Amrah, S. (2018). Antifungal effect of three local Malaysian honeys on selected pathogenic fungi of otomycosis: An *in vitro* evaluation. *Journal of Young Pharmacists*, 10(4), 508-512.
- Zulkhairi Amin, F.A., Sabri, S., Mohammad, S.M., Ismail, M., Chan, K.W., Ismail, N. et al. (2018). Therapeutic properties of stingless bee honey in comparison with European bee honey. *Advances in Pharmacological Sciences*, 2018, 6179596.