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Biomechanical Analysis of Table Tennis Racket Performance Using Makassar Ebony Veneer: A Comparative Study

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ABSTRACT

Background of study: Sports equipment such as table tennis rackets have developed rapidly where the bounce factor related to the speed and control of the table tennis racket plays an important role in determining the victory of athletes. A bad racket bounce can interfere with the game strategy. Therefore, developing a table tennis racket that improves speed and control is essential.
Aims and scope of paper: The main objective of this research is to analyze the biomechanical performance of a table tennis racket blade constructed with Makassar ebony veneer and to compare its attributes specifically speed and control with those of a high-end commercial racket.
Methods: This study applies a comparative design by comparing two types of rackets in the sport of table tennis. Two-dimensional kinematics analysis was also conducted using Kinovea software.
Result: Based on the results of the t-test with a non-parametric path, all variables showed a very significant difference with a p value of 0.00 (Sig < 0.05). However, there was one variable that did not show a significant difference, namely the velocity variable, with a p value of 0.05 (Sig < 0.05). If examined from the average value, the speed variable has a slight difference, namely only a difference of 0.5. The average speed data, shows that the macassar ebony wood veneer racket has better speed.
Conclusion: Based on the results of biomechanical analysis, the reflection of the Makassar ebony wood veneer racket makes a good contribution to the speed and control of the table tennis racket. This finding has practical implications for designing an effective table tennis athlete smash and block game by utilizing the speed and control of a table tennis racket using Makassar ebony wood veneer.

INTRODUCTION

Table tennis is a sport known for its rapid gameplay, requiring a blend of physical agility, cognitive focus, and technical precision (Han, 2022). It is also recognized as a professional Olympic sport played competitively in over 200 countries (Mousset et al., 2021). Its popularity stems from the minimal space required to play and the relatively low cost of equipment, making it accessible across economic and geographic boundaries (Zhu et al., 2022). However, what often appears as a simple rally across a small table is, in reality, a complex interplay of biomechanics, materials science, and human performance (W. Li et al., 2023). Central to this performance is the racket a seemingly basic tool that, in reality, plays a pivotal role in dictating the dynamics of the game. The effectiveness of a player's performance in generating topspin, controlling trajectory, absorbing impact, and manipulating ball speed is significantly influenced by the structural properties and materials used in their racket (Jia et al., 2025). Sports equipment such as table tennis rackets have developed rapidly where the bounce factor related to the speed and control of the table tennis racket plays an important role in determining the victory of athletes (Chou et al., 2025). A bad racket bounce can interfere with the game strategy (Lu et al., 2024). Therefore, developing a table tennis racket that improves speed and control is essential.

The modern table tennis racket has evolved beyond its rudimentary beginnings to become a highly engineered piece of sporting equipment (Lees, 2003). The International Table Tennis Federation (ITTF) stipulates that at least 85% of a racket's blade must be made of natural wood by thickness, though additional layers of composite materials such as carbon or glass fibers are allowed under specific limitations (Deng et al., 2020). These regulatory parameters have spurred innovation in blade construction, with manufacturers and researchers alike exploring combinations of natural and synthetic materials to enhance racket performance (X. Y. Li, 2022). Table tennis rackets are also changing with the spread of composite materials. A racket blade made of wood can consist of 7 layers (Yıldızbaş et al., 2022). Typically, the racket blade comprises 5 to 7 layers, including inner and outer veneers, sometimes reinforced with carbon fiber, arylate, or glass fiber to optimize mechanical properties such as stiffness, elasticity, vibration control, and ball rebound characteristics.

A comprehensive body of literature has analyzed how material composition and construction techniques influence racket performance (X. Y. Li, 2022). The inclusion of carbon fiber layers can significantly enhance stiffness and reduce vibration amplitude, allowing for a quicker energy transfer and a more predictable rebound path of the ball (Yin et al., 2024). The elastic modulus, density, and fiber orientation in racket layers greatly affect the power output and control characteristics of a racket. Moreover, blade mass and balance point have been shown to influence swing dynamics and stroke timing, affecting player fatigue and consistency. Sponge thickness and rubber hardness interact with blade stiffness, creating a complex system where material synergy becomes a determinant of performance.

In terms of wood selection, research has extensively documented the use of imported high-quality woods (Bao et al., 2025), like Hinoki (Japanese cypress), Limba, and Kiri (Paulownia), each offering specific performance attributes. Hinoki, for example, is renowned for its soft touch and excellent feedback, making it a favorite for offensive players relying on topspin. Limba provides a balanced feel and is typically used in the outer ply for better control. Meanwhile, lightweight woods such as Balsa or Ayous are often used in the core for their shock absorption and flexibility. However, much of this research has been oriented around materials sourced and manufactured outside of Indonesia, thereby limiting the scope for integrating local resources into high-performance racket production. This poses a significant gap, particularly in the context of Indonesia a country endowed with a rich diversity of timber species, many of which remain underexplored in the domain of sports engineering and equipment innovation.

This study seeks to address that very gap by investigating the potential of Makassar ebony (Diospyros celebica), a native Indonesian hardwood, as a core veneer material in table tennis rackets. Known for its exceptional hardness, density, and aesthetic appeal, Makassar ebony has traditionally been used in furniture, musical instruments, and decorative items. Its distinct grain pattern and mechanical durability place it in the same class as globally respected woods such as Rosewood. The wood's high modulus of elasticity and compressive strength suggest promising characteristics for performance sports equipment, particularly where control, consistency, and speed are crucial. However, scientific research evaluating its application in racket construction especially through quantitative biomechanical metrics remains scarce. Integrating such local materials not only offers the opportunity to diversify the global market but also strengthens the capacity of Indonesia's domestic sports industry through innovation and resource utilization.

Makassar ebony's anatomical properties make it a compelling candidate for veneer layers in offensive-style racket blades. Its dense grain structure enhances vibration damping, which contributes to a better feel and control when the ball impacts the racket. At the same time, its hardness and stiffness offer a higher rebound coefficient, potentially translating to increased ball speed. The veneer also carries a unique aesthetic striped black and reddish-brown hues which adds a layer of market appeal from a design perspective. When combined with other complementary materials such as Ayous, Balsa, and carbon fiber each strategically layered for balance, weight distribution, and elasticity a composite blade using Makassar ebony veneer could present a competitive alternative to existing commercial rackets.

In this study, the newly developed racket blade follows a seven-layer configuration consisting of outer and inner layers of Makassar ebony veneer, reinforced with carbon fiber and supported by Balsa as the core layer. This design was compared biomechanically with a leading commercial model the Stiga Cybershape Carbon Truls Edition, a racket known for its offensive properties and cutting-edge blade geometry. Using a controlled experimental setting with consistent robotic ball launching parameters and 2D motion capture analysis via Kinovea software, the two rackets were tested for performance indicators such as speed, acceleration, trajectory, and control consistency. This direct comparative approach allows for an objective evaluation of the Makassar ebony veneer blade's biomechanical performance.

The rationale for this study is twofold. First, it introduces a novel material into the high-performance sports equipment domain, testing its functional viability under real-world conditions. Second, it supports a broader national initiative to harness Indonesia's natural resources for value-added product innovation. By validating the efficacy of locally sourced materials such as Makassar ebony in international-standard sports gear, the study not only contributes to academic knowledge but also potentially stimulates industrial development and national branding. The convergence of biomechanics, materials science, and sustainable manufacturing opens new pathways for localized innovation in a field historically dominated by imported goods and technologies.

Moreover, the study responds to the growing demand for sustainable and ethically sourced materials in sports manufacturing. With increasing attention on the environmental and social impact of global production chains, utilizing locally available hardwoods could reduce transportation-related emissions, support local forestry economies, and promote responsible material sourcing. From an educational and scientific standpoint, the study also provides a model for interdisciplinary collaboration, merging insights from sports science, mechanical engineering, and natural resource management to solve complex performance and sustainability challenges.

The main objective of this research is to analyze the biomechanical performance of a table tennis racket blade constructed with Makassar ebony veneer and to compare its attributes specifically speed and control with those of a high-end commercial racket. It is

hypothesized that the Makassar ebony veneer racket will offer equivalent or superior control while maintaining competitive speed metrics, validating its suitability for offensive-style play. The research further posits that the mechanical advantages of Makassar ebony, when properly integrated into blade construction, can produce a racket that meets or exceeds the functional standards required for competitive play.
This study offers a compelling intersection of indigenous resource utilization and scientific innovation. Through its findings, the research aims to contribute to the broader discourse on material performance, racket technology, and the potential for local hardwood species to serve in elite sports contexts. The success of this experiment could pave the way for the mass production of Indonesian-made rackets that are not only functional but also rooted in cultural and ecological identity. In doing so, it promotes not just athletic performance but also national pride and global recognition in the realm of sports technology.

RESEARCH METHOD

The study used a comparative experimental design to evaluate the biomechanical performance of two different table tennis rackets: Garuda Unesa Speed (GUS) made with Makassar ebony veneer, and commercial rackets (comparison racket) used by professional athletes. Both rackets are categorized as offensive types and possess similar structural specifications, including a 7-ply composition (5 layers of wood and 2 layers of carbon fiber), 6.2 mm blade thickness, and an approximate weight of 95 grams.

Examples of equipment studied in this study are garuda unesa speed (GUS) table tennis rackets that use Makassar ejection veneers and commercial rackets (comparison racket) used by professional athletes. 100 balls of the Double Fish V40+ brand (China) are thrown to both rackets to see the speed and control of the bounce.

This research instrument uses a Sony Alpha 6400 digital camera equipped with a G Master 18–105mm lens, a robot ball launcher (Xiom i5 robot, Korea), a Xiom Pro 9 table, and the Kinovea 2D application to measure the ball's bounce on a table tennis racket related to speed and control.

The initial stage of the data collection implementation process was to make camera adjustments related to camera height and visual distance from the camera to the table tennis table (Figure 1). The researcher set the camera height at 1.5 meters and the camera distance from the table at 5 meters. The determination was made so that the video results could be optimized in terms of proportions, so as not to provide challenges when two-dimensional analysis was carried out. Then, the researcher determined the position of the tested table tennis racket and the table tennis ball thrower. The position of the ejection device is parallel to the position of the table tennis racket to be tested, and the height of the two is 1 meter. This parallel position allows the results of the ball bounce to be straight, and minimizes the results of inappropriate bounces.
The rackets were statically mounted using a fixed metal clamp support to maintain their stability and angle at the center of the table. This ensured that all incoming balls struck

the racket at the same location and angle, eliminating variability due to human factors. The purpose of this setup was to isolate the racket's biomechanical properties (e.g., rebound speed and control) from other external influences such as user technique or motion.

To ensure experimental consistency, a robotic ball launcher (Robot Xiom i5, Korea) was used to deliver balls at controlled speeds, angles, and frequencies to the rackets. The robot was positioned in the middle of the opposite court and programmed for topspin shots using the following settings:

- ✓ Upper wheel speed: level 6
- ✓ Lower wheel speed: level 4
- ✓ Ball frequency: level 9

The balls used for testing were 100 Double Fish V40+ (China), ITTF-approved plastic balls, ensuring uniform quality and rebound properties across trials. Each racket was fitted with a Stiga DNA Hybrid Sponge rubber for consistency across tests.

The trajectory, speed, and control data of the ball after impact with each racket were recorded using a **Sony Alpha 6400 digital camera** fitted with a **G Master 18–105mm lens**, mounted perpendicular to the table to capture accurate motion paths. The videos were analyzed using **Kinovea 2D motion analysis software**, which enabled frame-by-frame tracking of key biomechanical variables, including:

- ✓ Rebound speed (m/s)
- ✓ Acceleration (m/s²)
- ✓ Rebound distance (cm)
- ✓ Maximum height (cm)
- ✓ Ball flight time (s)
- ✓ Trajectory length (cm)
- ✓ Vertical and horizontal velocity
- ✓ Vertical and horizontal acceleration

Each of the 100 shots was evaluated per racket, and average values were calculated for comparison across variables.

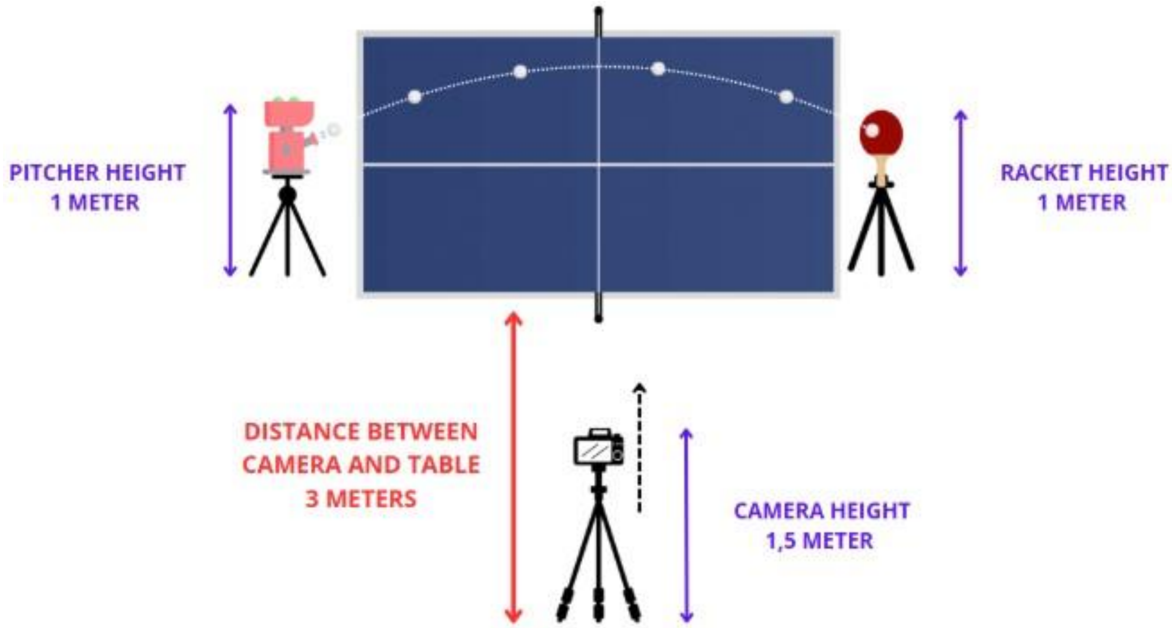

Figure 1. Research Procedure

This analysis includes two stages, the first is descriptive analysis and normality to examine the distribution of data. Then, the second is comparative analysis using the T test or different test.

Descriptive statistics were used to summarize the mean values of each biomechanical parameter for both rackets. Comparative analysis focused on the difference in:

- ✓ Rebound speed and distance as indicators of power and explosiveness
- ✓ Height and trajectory length as indicators of spin and flight arc
- ✓ Horizontal and vertical velocity and acceleration as indicators of control and energy transfer

These data points were used to determine which racket design provided better performance outcomes under identical testing conditions.

RESULTS AND DISCUSSION

Descriptive Analysis

Based on the results of the descriptive analysis, it is known that there are 10 variables examined in this study. These variables represent the speed and control of the developed racket and the comparison racket. The descriptive analysis in Table 2 and Table 3 shows that the distribution of data from both racket analysis results is abnormal (Sig > 0.05). However, there are several variables that show normal data distribution results. These variables are the speed and height of the two rackets, as well as the distance variable of the comparison racket.

Table 1. Descriptive Analysis of Veener Eboni Makassar Racket.

Variabel	N	Mean	SD	Min.	Max.	P-Value
Time	90	0.72	0.04	0.62	0.82	0.00
Speed	90	4.56	0.21	3.99	5.36	0.20*
Distance	90	263.96	15.20	215.31	292.70	0.00

Height	90	80.56	6.19	60.11	98.78	0.14*
Length	90	293.89	34.55	85.27	335.76	0.00
Vertical Velocity	90	0.30	0.32	-2.50	0.82	0.00
Horizontal Velocity	90	3.50	0.88	-2.31	4.20	0.00
Acceleration	90	-0.70	2.32	-7.81	11.82	0.00
Vertical Acceleration	90	9.59	1.66	4.79	16.30	0.01
Horizontal Acceleration	90	-1.22	2.18	-4.29	13.47	0.00

*Sig > 0.05

Table 2. Descriptive Analysis of Comparison Racket

Variabel	N	Mean	SD	Min.	Max.	P-Value
Time	90	0.66	0.03	0.58	0.73	0.00
Speed	90	4.51	0.17	4.07	4.94	0.20*
Distance	90	249.58	12.00	220.51	273.42	0.20*
Height	90	72.94	4.93	62.73	84.73	0.17*
Length	90	274.92	20.72	178.86	305.33	0.00
Vertical Velocity	90	-0.34	0.08	-0.84	-0.25	0.00
Horizontal Velocity	90	-3.66	0.50	-4.07	-0.66	0.00
Acceleration	90	-1.78	1.92	-5.67	8.20	0.00
Vertical Acceleration	90	-9.42	1.54	-17.66	-5.85	0.01
Horizontal Acceleration	90	2.55	1.41	-6.80	5.24	0.00

*Sig > 0.05

Comparative Analysis

T-tests were conducted in this study to determine the comparative results of the two rackets tested. Although it can be clearly observed through the mean value in the previous descriptive analysis results, a t-test must still be carried out so that the differences seen can be validated accurately. Based on the results of the t-test with the non-parametric path, all variables showed a highly significant difference with a p-value of 0.00 (Sig < 0.05). However, there is one variable that does not show a significant difference, namely the speed variable, with a p-value of 0.05 (Sig < 0.05). If examined from the mean value, the speed variable has a slight difference, which is only a difference of 0.5. The mean speed data, shows that the developed racket or the macassar ebony veener racket, has a speed superior to the comparison racket. This certainly proves that the developed racket is suitable for attacking or offensive playing styles, such as performing drive and smash techniques.

Table 4. Result of Comparative Analysis

Variabel	Mean		P-Value
	Veener	Cyber	
Time	0.72	0.66	0.00*
Speed	4.56	4.51	0.05

Distance	263.96	249.58	0.00*
Height	80.56	72.94	0.00*
Length	293.89	274.92	0.00*
Vertical Velocity	0.30	-0.34	0.00*
Horizontal Velocity	3.50	-3.66	0.00*
Acceleration	-0.70	-1.78	0.00*
Vertical Acceleration	9.59	-9.42	0.00*
Horizontal Acceleration	-1.22	2.55	0.00*

*Sig < 0.05

Kinematic Analysis

Figure 2. Ball Trajectory of Veneer Eboni Makassar Racket

The results of the two-dimensional kinematics analysis show how the ball bounce direction of the two tested rackets (Figure 2 and Figure 3). The results visualize the difference in the stability of the ball rebound direction, through the color lines shown in the figures. The ball bounce direction from figure 3 looks more stable than the ball bounce direction from figure 2. It can be observed that in figure 3, there is no direction of the ball's reflection that points backwards. Whereas in figure 2, there are 2 colors that show the direction of the ball's reflection towards the back of the racket.

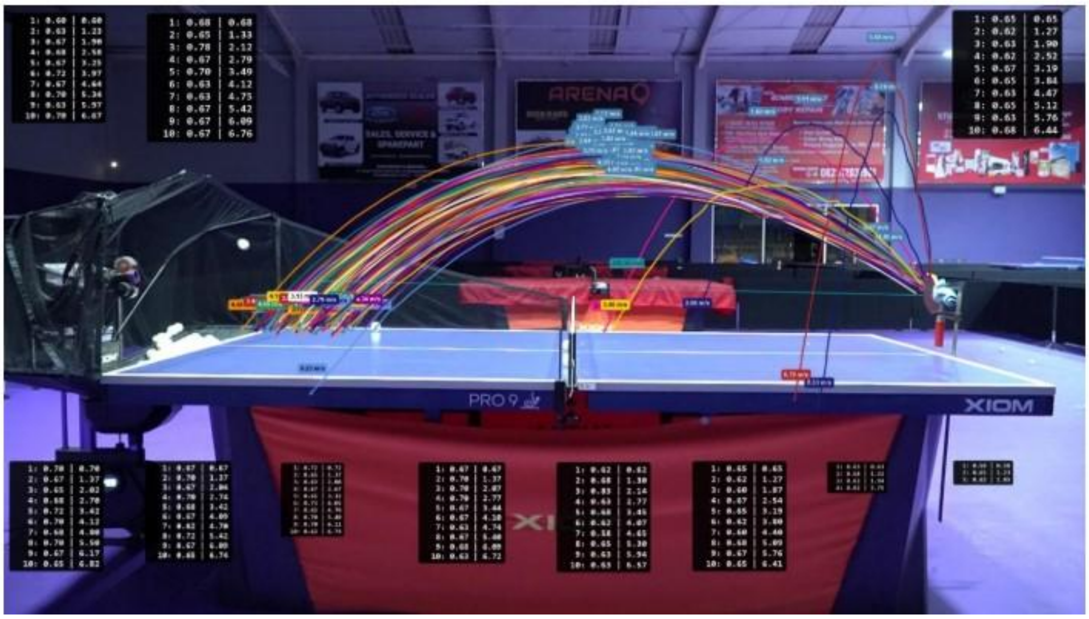

Figure 3. Ball Trajectory of Comparison Racket

Although figure 3 presents more stable data than figure 2, in figure 2 the ball bounce results appear to have a longer and higher range. These results indicate that the racket being developed by the researchers has superior ball control than the racket used for comparison. Through a higher bounce, and a longer range, of course this racket also has characteristics that are suitable for defensive play, such as chopping techniques.

This study aimed to examine the biomechanical performance of a table tennis racket made with Makassar ebony veneer compared to a commercial standard racket (comparison racket). The comparison was grounded on experimental data and supported by statistical analysis using the Mann-Whitney U Test for non-parametric evaluation. The variable discussed here is reaction time (TIME) a critical indicator of control and efficiency in table tennis performance. The results demonstrate significant differences in time performance between the two racket types, thereby validating the impact of blade composition and material characteristics on biomechanical outcomes.

The results of the Mann-Whitney U test produced a U value of 1094.5 and a Z score of -8.453, with $p < 0.001$, indicating a statistically significant difference between the ebony racket group and the comparison racket group in terms of rebound time. The average ranking for the ebony racket was 122.34, substantially higher than that of the comparison racket at 57.30. This ranking indicates that the Makassar black veneer racket shows a longer rebound time than the comparison racket. These findings imply a greater dwell time, which, in the context of racket sports, can translate to improved control and potential spin. A longer contact time between the ball and the racket may give players a better ability to direct shots and apply nuanced spin, supporting the hypothesis that Makassar black wood can contribute to enhanced control characteristics.

From a biomechanical perspective, the increase in rebound time is associated with the material stiffness and vibration damping properties inherent to Makassar ebony. As a dense hardwood with a high modulus of elasticity, Makassar ebony likely reduces the energy loss during ball impact, enabling the blade to absorb and return energy more uniformly. This translates into consistent ball trajectories and predictable rebounds, which are critical for professional play. The Makassar racket's construction featuring a 7-ply structure with carbon fiber reinforcement and a Balsa core may have further contributed to this performance by balancing rigidity and shock absorption. This configuration optimizes the time-energy exchange between the ball and the racket blade. In contrast, the comparison racket, though a high-performance commercial product, emphasizes speed and aggressive offensive play. It is designed with a unique hexagonal geometry and optimized weight distribution, features that cater to players who prioritize fast rallies and powerful strokes. The shorter rebound time observed in the comparison racket (mean rank = 57.30) reflects its rapid response and minimal dwell time, favoring explosive shots and direct counters. However, such characteristics might compromise control in favor of speed, particularly in players who require more nuanced ball placement and varied spin.

The results affirm that racket composition significantly affects performance variables such as speed, control, and reaction time. Previous literature supports this conclusion. Studies by (Wang, 2012) and (Buragohain, 2017) emphasize that the type of wood and layering technique in racket construction influence mechanical properties like vibration frequency, elasticity, and impact response. Furthermore, (Miyazawa et al., 2020) established that composite blades with carbon reinforcement improve energy transfer but may increase rigidity beyond a threshold optimal for control. The research conducted by (Zhou et al., 2021) states that a good racket can adapt to various unconventional playing styles and successfully alter the ball's trajectory and increase speed. Table tennis rackets based on anisotropic electrorheological elastomers (EREs) have been developed. On premium table tennis rackets, many players opt for composite blades that offer the perfect balance between speed and control. Rackets designed with the needs of professional players in mind ensure every shot is precise and strong (Kumamoto et al., 2025). Understanding the composition of the racket, playing style, and character of the player can make informed decisions that improve the game (Brich et al., 2024). (Lanzoni et al., 2021) states as an all-rounder, control is important, therefore it is necessary to choose a bar that offers excellent control. Players focus on taking control through topspin, and prefer a safer, more controlled style (Iino & Kojima, 2016).

(Wong et al., 2020) identified that table tennis biomechanics reported findings that compared differences between different games level and movement tasks (handwork or footwork), using ball and racket speed. (Iino & Kojima, 2016) investigated the influence of racket mass and stroke rate on the kinematics and kinetics of racket rods and arms in backhand topspin table tennis. The mass of the racket does not significantly affect all kinematics. (Bańkosz & Winiarski, 2018) stated that the speed of the racket is correlated with the angle speed in the forehand topspin while angular speed can substantially affect the speed of the racket when one changes the type of stroke. The ability to generate a high racket speed and a large amount of racket kinetic energy on impact is important for table tennis players (Iino & Kojima, 2016). (C. Liu et al., 2012) proposes a racket control method for returning a table tennis ball to a desired position with a desired rotational velocity. The method determines the racket's state, i.e., the racket's striking posture and translational velocity by using two physical models: racket rebound model and aerody namics model. (Tabrizi et al., 2020) stated that rackets make it possible to collect player hit time series data in a responsive and sensitive manner.

Furthermore, (Rinaldi et al., 2019) stated that the performance of table tennis rackets is often associated with subjective or quantitative criteria such as adhesion, control, and speed. Overall, so-called performance aims to characterize impact with the ball. With the continuous development of table tennis, and the faster, spinning ball becoming stronger, this requires an increasingly higher quality and specification of table tennis equipment (J. Q. Liu et al., 2014). Modern table tennis rackets are made of composite materials with the ratio of stiffness to weight due to the rebound speed and topspin of the ball increases with the speed of the resulting impact (Sun et al., 2012). Each racket has the right composition which is determined by the number of layers, the wood and its thickness and several layers of carbon have been introduced to improve the rigidity and speed of the racket (Manin et al., 2012). The racket is the only part of the equipment that can be felt directly, which serves as contact between the hand and the ball. High-level players always emphasize the importance of choosing the right racket. The present study demonstrates that the Makassar ebony veneer offers a balanced alternative providing adequate speed while enhancing ball dwell time for better handling.

This performance is not only biomechanically significant but also strategically relevant for the sport (Langitan, 2018). Players whose style revolves around precision, spin variation, and strategic placement may benefit more from rackets with slightly longer dwell times. Defensive and all-round players, in particular, often seek rackets that enable them to absorb incoming speed and redirect it with better accuracy. The Makassar ebony veneer appears to fulfill this niche by providing stability during contact and reducing vibration inconsistencies that can lead to error margins during high-speed exchanges.

Despite these limitations, the data strongly suggest that the Makassar ebony veneer racket offers a promising blend of speed and control, suitable for modern competitive table tennis. Its performance, validated by statistical significance, not only supports its functional use but also encourages continued innovation in local sports equipment manufacturing. Further studies should explore other indigenous hardwoods with unique mechanical properties and test them across different play styles, racket geometries, and environmental conditions.

In conclusion, comparative biomechanical analysis between Garuda Unesa Speed (GUS) rackets made with Makassar ebony veneer and commercial rackets (comparison racket) revealed that GUS rackets showed better control characteristics through longer residence times. This finding supports the hypothesis that Makassar ebony is a viable material for high-performance table tennis equipment, offering an ideal balance between power and precision. The integration of locally sourced materials into competitive sports gear opens avenues for innovation, sustainability, and national industry development, aligning with broader goals in sport science and technological advancement.

Implications:

The biomechanical analysis of the bounce of table tennis rackets using Makassar ebony wood veneer related to speed and control can provide an idea and be utilized by coaches and athletes. This racket can be used for smash and block in table tennis games. Athletes who need good control and speed can use this racket. Another critical dimension of this study is the utilization of local, sustainable materials in high-performance sports equipment. The application of Makassar ebony, a native Indonesian hardwood, underscores the potential for national material innovation in a field traditionally dominated by imported resources. The wood's density, durability, and visual appeal place it among elite materials such as Hinoki and Rosewood, yet it remains underutilized in racket manufacturing. The successful performance of this racket model in controlled experiments adds credibility to the idea that local industries can develop internationally competitive products using indigenous resources. This approach not only boosts national pride and economic self-reliance but also contributes to sustainability by reducing reliance on foreign materials with high ecological footprints.

Research Contribution

The findings show that the Makassar ebony veneer racket produced significantly longer rebound times compared to the commercial racket (comparison racket) model. The extended dwell time associated with the Makassar ebony racket indicates superior control and enhanced ball feel, which are crucial for executing precise shots, strategic ball placement, and spin variation. These results validate the hypothesis that the use of Makassar ebony a dense, strong, and naturally aesthetic wood can yield performance benefits in racket construction, especially in areas related to stability and control.

From a biomechanical standpoint, the increased contact time and smoother rebound behavior can be attributed to the material properties of Makassar ebony, which include high hardness, stiffness, and vibration damping capability. When combined with a 7-ply construction that includes carbon fiber reinforcement and a Balsa core, the Makassar ebony veneer delivers a balanced response profile that supports controlled yet powerful play. This makes the racket particularly suitable for players who rely on tactical maneuvering, consistent returns, and defensive counterattacks.

The study contributes not only to the field of sport biomechanics but also to sports engineering and local innovation. By demonstrating the functional viability of indigenous Indonesian materials in high-performance sports equipment, this research underscores the untapped potential of natural resources in supporting the domestic sports industry. Makassar ebony, with its excellent mechanical properties and cultural significance, emerges as a promising alternative to commonly imported woods such as Hinoki or Limba. The findings encourage manufacturers, researchers, and policymakers to further explore and invest in sustainable and locally sourced material innovation.

Limitations

Despite the positive outcomes, the study acknowledges several limitations. The experimental setup used static racket placement and a robotic ball launcher, which ensured high internal validity but may not fully capture the dynamics of human gameplay. Additionally, the biomechanical parameters were limited to rebound time and trajectory analysis. While the study minimized variability through robot-assisted delivery and fixed racket positioning, it did not account for human handling, grip differences, or real-game dynamic conditions. Additionally, a small portion of test shots (10 for the ebony racket and 8 for the commercial racket) did not result in perfect contact, leading to minor data exclusions.

Suggestions

Future research should incorporate dynamic testing with players, include spin and angular velocity as additional variables, and apply 3D motion capture technologies to gain a deeper understanding of racket performance under competitive conditions. Nevertheless, the findings must be interpreted in light of the study's limitations. First, the experimental design involved a static racket setup using a robotic launcher, thereby excluding human grip variability, wrist action, and stroke techniques that occur during actual gameplay. While this approach was suitable for isolating material effects and ensuring consistent testing conditions, future research should include dynamic trials with human subjects to validate findings in real-play scenarios. Second, although rebound time is a meaningful indicator of control, a broader range of biomechanical variables such as spin rate, angular velocity, and energy transfer efficiency could provide a more holistic evaluation. Incorporating 3D motion analysis or high-speed photometry may yield deeper insights into racket-ball interactions.

CONCLUSION

In conclusion, there is a difference in the speed and bounce control of the table tennis racket using Makassar ebony wood veneer with the commercial racket (comparison racket) used by professional athletes. Based on the results of biomechanical analysis, the reflection of the Makassar ebony wood veneer racket makes a good contribution to the speed and control of the table tennis racket. This finding has practical implications for designing an effective table tennis athlete smash and block game by utilizing the speed and control of a table tennis racket using Makassar ebony wood veneer. The Makassar ebony veneer racket demonstrates strong potential as a high-performance alternative in the global table tennis market. Its biomechanical advantages in control and consistency, coupled with its local origin and sustainability, position it as a noteworthy innovation in both sport science and product development. This study paves the way for further interdisciplinary collaboration between material science, sports engineering, and national industry, ultimately contributing to Indonesia's presence in the world of competitive sport technology.

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REFERENCES

Bańkosz, Z., & Winiarski, S. (2018). Correlations between Angular Velocities in Selected Joints and Velocity of Table Tennis Racket during Topspin Forehand and Backhand. Journal of Sports Science & Medicine, 17(2), 330. https://pmc.ncbi.nlm.nih.gov/articles/PMC5950751/

Bao, W., Tan, Y., Ying, Z., Xue, R., Xu, X., Duan, S., Lin, H., & Chen, H. (2025). An Investigation of the Mechanical Properties of Ti Films Reinforced with Wood Composites by Growing Ti Particles on a Wood Substrate. Polymers, 17(5), 583. https://doi.org/10.3390/POLYM17050583/S1

Brich, Q., Casals, M., Crespo, M., Reid, M., & Baiget, E. (2024). Quantifying Hitting Load in Racket Sports: A Scoping Review of Key Technologies. International Journal of Sports Physiology and Performance, 19(6), 519–532. https://doi.org/10.1123/IJSPP.2023-0385

Buragohain, M. K. (2017). Composite structures: Design, mechanics, analysis, manufacturing, and testing. Composite Structures: Design, Mechanics, Analysis, Manufacturing, and Testing, 1–732. https://doi.org/10.1201/9781315268057/COMPOSITE-STRUCTURES-MANOJ-KUMAR-BURAGOHAIN/RIGHTS-AND-PERMISSIONS

Chou, C. Y., Chen, Z. H., Sheu, Y. H., Chen, H. H., Sun, M. Te, & Wu, S. K. (2025). TTSwing: a Dataset for Table Tennis Swing and Racket Kinematics Analysis. Scientific Data , 12(1), 1–9. https://doi.org/10.1038/S41597-025-04680-Y;SUBJMETA=166,639,692,700;KWRD=ENGINEERING,HEALTH+CARE

Deng, J., Wei, X., Zhou, H., Wang, G., & Zhang, S. (2020). Inspiration from table tennis racket: Preparation of rubber-wood-bamboo laminated composite (RWBLC) and its response characteristics to cyclic perpendicular compressive load. Composite Structures, 241. https://doi.org/10.1016/j.compstruct.2020.112135

Han, L. (2022). A Table Tennis Motion Correction System Based on Human Motion Feature Recognition. Security and Communication Networks, 2022. https://doi.org/10.1155/2022/7049429

Iino, Y., & Kojima, T. (2016). Effect of the racket mass and the rate of strokes on kinematics and kinetics in the table tennis topspin backhand. Journal of Sports Sciences, 34(8), 721–729. https://doi.org/10.1080/02640414.2015.1069377,

Jia, M., Sun, B., Jia, M., Liu, Y., & Zhang, D. (2025). Comparative study on the performance of different table tennis rubbers. Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology. https://doi.org/10.1177/17543371241310338;CSUBTYPE:STRING:AHEAD

Kumamoto, R., Loh, P. Y., He, Y., Ferlinghetti, E., Lancini, M., & Uno, T. (2025). Impacts of Racket Handle Design on Table Tennis Topspin Forehand Rally Performance Among Beginner Players. Sports 2025, Vol. 13, Page 22, 13(1), 22. https://doi.org/10.3390/SPORTS13010022

Langitan, F. W. (2018). The Influence of Training Strategy and Physical Condition toward Forehand Drive Ability in Table Tennis. IOP Conference Series: Materials Science and Engineering, 306(1), 012043. https://doi.org/10.1088/1757-899X/306/1/012043

Lanzoni, I. M., Bartolomei, S., Michele, R. Di, Gu, Y., Baker, J. S., Fantozzi, S., & Cortesi, M. (2021). Kinematic Analysis of the Racket Position during the Table Tennis Top Spin Forehand Stroke. Applied Sciences 2021, Vol. 11, Page 5178, 11(11), 5178. https://doi.org/10.3390/APP11115178

Lees, A. (2003). Science and the major racket sports: A review. Journal of Sports Sciences, 21(9). https://doi.org/10.1080/0264041031000140275

Li, W., Liu, X., An, K., Qin, C., & Cheng, Y. (2023). Table Tennis Track Detection Based on Temporal Feature Multiplexing Network. Sensors, 23(3). https://doi.org/10.3390/s23031726

Li, X. Y. (2022). Study on The Performance of Table Tennis Racket Made of Carbon Fiber By Numerical Simulation. Journal of Technology, 37(3).

Liu, C., Hayakawa, Y., & Nakashima, A. (2012). Racket control and its experiments for robot playing table tennis. 2012 IEEE International Conference on Robotics and Biomimetics, ROBIO 2012 - Conference Digest, 241–246. https://doi.org/10.1109/ROBIO.2012.6490973

Liu, J. Q., Wang, B., Zhao, X., & Dou, Y. (2014). The Application of Rubber Materials on Table Tennis Racket. Applied Mechanics and Materials, 473, 116–120. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMM.473.116

Lu, Y., Ren, J., Wang, J., & Wang, Y. (2024). Effect of table tennis balls with different materials and structures on the hardness and elasticity. PLOS ONE, 19(4), e0301560. https://doi.org/10.1371/JOURNAL.PONE.0301560

Manin, L., Poggi, M., & Havard, N. (2012). Vibrations of table tennis racket composite wood blades: modeling and experiments. Procedia Engineering, 34, 694–699. https://doi.org/10.1016/J.PROENG.2012.04.118

Miyazawa, Y., Hadano, A., & Tanaka, K. (2020). Effects of Pimple Height of a Table Tennis Rubber on Ball Rebound Behavior. Proceedings 2020, Vol. 49, Page 55, 49(1), 55. https://doi.org/10.3390/PROCEEDINGS2020049055

Mousset, K., Violette, L., & Épron, A. (2021). The ITTF and Olympic recognition of table tennis: from pure amateurism to the Asian markets (1926–1988). Sport in History, 41(4). https://doi.org/10.1080/17460263.2021.1919187

Rinaldi, R. G., Manin, L., Moineau, S., & Havard, N. (2019). Table Tennis Ball Impacting Racket Polymeric Coatings: Experiments and Modeling of Key Performance Metrics. Applied Sciences 2019, Vol. 9, Page 158, 9(1), 158. https://doi.org/10.3390/APP9010158

Sun, W. M., Zhang, S. Q., & Hao, S. R. (2012). The Soleplate Materials and Performance of Table Tennis Bat with the Composite Properties of Materials in Material Engineering. Advanced Materials Research, 583, 232–235. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMR.583.232

Tabrizi, S. S., Pashazadeh, S., & Javani, V. (2020). Data acquired by a single object sensor for the detection and quality evaluation of table tennis forehand strokes. Data in Brief, 33, 106504. https://doi.org/10.1016/J.DIB.2020.106504

Wang, J. (2012). Application of Composite Materials on Sports Equipments. Applied Mechanics and Materials, 155–156, 903–906. https://doi.org/10.4028/WWW.SCIENTIFIC.NET/AMM.155-156.903

Wong, D. W. C., Lee, W. C. C., & Lam, W. K. (2020). Biomechanics of Table Tennis: A Systematic Scoping Review of Playing Levels and Maneuvers. Applied Sciences 2020, Vol. 10, Page 5203, 10(15), 5203. https://doi.org/10.3390/APP10155203

Yin, T., Hao, L., Zhao, X., Fu, Z., Liu, C., & He, S. (2024). Dynamic characteristics and mechanisms of table tennis blades with the inclusion of special fiber laminates[含有特种纤维夹层的乒乓球拍底板动特性与机制]. Fuhe Cailiao Xuebao/Acta Materiae Compositae Sinica, 41(3), 1626–1632. https://doi.org/10.13801/j.cnki.fhclxb.20230703.002

Yıldızbaş, A., Özlüsoylu, İ., İstek, A., Tenisi Raket Tahtası Üretimi ve Özellikleri, M., Endüstri Mühendisliği Bölümü, O., Fakültesi, O., Üniversitesi, B., & Makale Tarihçesi, T. (2022). Table Tennis Blade Production and Features. Bartın Orman Fakültesi Dergisi, 24(2), 394–404. https://doi.org/10.24011/BAROFD.1085278

Zhou, X., Wang, L., Huang, D., Liang, Y., Shi, Q., Yaying, H., Zhang, M., Pu, H., Wen, W., & Wu, J. (2021). Smart Table Tennis Racket with Tunable Stiffness for Diverse Play Styles and Unconventional Technique Training (Adv. Mater. Technol. 10/2021). Advanced Materials Technologies, 6(10), 2170056. https://doi.org/10.1002/ADMT.202170056

Zhu, X., Zhang, M., Wang, X., Jia, C., & Zhang, Y. (2022). A Portable and Low-Cost Triboelectric Nanogenerator for Wheelchair Table Tennis Monitoring. Electronics (Switzerland), 11(24), 4189. https://doi.org/10.3390/ELECTRONICS11244189/S1