

“Experimental Investigation of Corncob Charcoal as a Sustainable Carbonaceous Fuel for Composite Solid Propellants”

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ABSTRACT

This current scientific exposition rigorously investigates the foundational physicochemical traits governing solid composite propellants engineered through a direct comparative analysis bridging two distinctly unique carbonaceous materials namely the organically harvested corncob charcoal against the standardized activated carbon baseline. Deploying an uncompromisingly strict quantitative experimental framework dictates the formulation of test specimens utilizing an exact compositional ratio encompassing 75% potassium nitrate acting as the primary oxidizer fused seamlessly alongside 15% carbonaceous substance and 10% sulfur before subjecting these precise mixtures toward exhaustive empirical evaluations encompassing rigorous density measurements alongside definitive combustion velocity tracking and raw propulsive thrust quantification culminating in the exact calculation of specific impulse alongside the paramount thrust-to-weight ratio.

The experimental results revealed significant differences between the two carbonaceous materials separating these two distinctly utilized combustible materials. Activated carbon demonstrated superior propulsion performance compared with corncob charcoal by miraculously generating a 32.5% superior specific impulse magnitude peaking flawlessly at 79.07 seconds while simultaneously maintaining an average TWR metric standing exactly 23.5% greater than the agricultural alternative whereas the organically formulated corncob refuse conversely exhibited better combustion stability regarding absolute combustion stability alongside unparalleled inter-sample consistency considering the maximum specific impulse deviation afflicting the botanical specimen reaches a minuscule 2.62 seconds thereby proving phenomenally more stable when positioned against the highly erratic industrial carbon counterpart enduring severe operational fluctuations hitting exactly 13.55 seconds. This overarching scientific breakthrough ultimately finalizes a concrete academic recommendation mandating the deployment of activated carbon constructs within advanced propulsion mechanisms desperately requiring massive kinetic surges while simultaneously designating the discarded corncob charcoal as the unequivocally ideal candidate powering ballistic rocket architectures strictly prioritizing an unwavering combustion profile devoid of excessive operational volatility.

Keywords: *Composite Solid Propellant; Corn Cob; Activated Carbon; Specific Impulse; Burning Rate; Charcoal.*

Introduction

The significant carbon emissions generated by military activities highlight the importance of developing alternative energy sources to support more sustainable defense systems [1]. Military activities contribute significantly to global greenhouse gas emissions due to their high energy consumption [2]. Such a substantial carbon footprint from the militaristic realm unequivocally amplifies the imperative necessity of assimilating alternative power sources into security infrastructures to aggressively decelerate rampant ecological degradation [2] [3]. The Indonesian government promptly countered this formidable predicament by formalizing a strategic mandate via Presidential Regulation Number 22 of 2017 concerning the National Energy Master Plan to drastically elevate the renewable power ratio until it reaches an ambitious 23% within the nationwide utility spectrum by the target year 2025 [4] [5].

Agricultural waste represents a promising renewable resource for alternative energy development since its massive production volume across the nation heavily fortifies domestic biomass inventories to secure energetic sovereignty [6] [7]. Analyzing the domestic corn yield statistics that relevant authorities continuously scrutinize reveals how the accumulated corncob leftovers supposedly hit an exceptionally prominent scale touching exactly 30% of the entire harvested mass equaling a residual product ratio of exactly 0.273 [8] [9] [10]. Scientific evaluations substantiate the inherent thermal capability of corncobs acting as an alternative combustible material considering rigorous laboratory diagnostics conclusively validate how this organic briquette calorific output effortlessly achieves highly competitive benchmarks suitable for extensive industrial deployments [11] [12] [13]. Utilizing agricultural residues can reduce environmental pollution while simultaneously increasing their economic value by actively halting the traditional open-air field incineration practices among rural cultivators while simultaneously

transforming all those heavily neglected botanical materials into highly pragmatic and ecologically enduring power generation instruments designed for long-term sustainability [6] [14] [15].

Aligning flawlessly with the 2025-2029 Indonesian Army Posture alongside the National Research Master Plan dictates how mastering rocket alongside propellant technologies constitutes an absolute apex national priority [16] [17]. Harnessing corncob refuse emerges as a tactical maneuver to slash reliance upon foreign raw materials feeding domestic military complexes [17]. Pioneering such organically derived ballistic propulsion architectures stands phenomenally pertinent acting as a tangible materialization of applied sciences underpinning sovereign martial fortitude since this exact scientific endeavor actively annihilates massive agrarian waste stockpiles whilst simultaneously supercharging national treasury conservation beyond conventional expectations [18] [19].

This study investigates the feasibility of using corncob charcoal as an alternative carbonaceous material in composite solid propellants [10] [20], alongside benchmarking its kinetic output metrics directly against coconut shell activated carbon mixtures [21]. Channeling cutting-edge technological engineering breakthroughs fused inextricably with uncompromising ecological endurance paradigms [22] [23] The study aims to evaluate the performance characteristics of biomass-based propellant formulations for potential defense applications flawlessly conquering rigorous operational thresholds mandated for advanced martial applications [17] [24] whilst concurrently expediting nationwide financial escalations purposefully marching toward the realization of the grand Advanced Indonesia vision [25] [26].

Research Methodology

This scientific investigation deploys a strictly quantitative experimental framework utilizing carbonized corncob charcoal as the paramount foundational substance alongside potassium nitrate or

KNO_3 acting as a potent oxidizing agent fusing seamlessly with sulfur operating as both a reaction catalyst and secondary combustible source before introducing organic dextrin to function as a natural binding agent while harnessing 70% alcohol to serve as the ultimate solvent dissolving the entire mixture. The operational apparatus mobilized for this intricate procedure encompasses polyvinyl chloride pipes functioning as temporary containment vessels alongside thermal dehydration ovens purposed to obliterate latent moisture content accompanied by precision calipers and traditional mortar and pestle sets partnering with highly accurate digital weighing scales before pushing the pulverized materials through a strict 100 mesh wire sieve to subsequently face immense physical compaction via mechanical press tools forcing the thoroughly mixed substance into definitive propellant molds directly following the achievement of absolute structural uniformity through an intensive ball mill homogenization mechanism.

Corncob biomass was first carbonized in an oven at 200°C for 3 hours utilizing high-capacity thermal ovens locked at 200°C across 3 full hours before letting the botanical remnants cool down entirely to undergo aggressive pulverization via conventional mortar and pestle mechanisms followed seamlessly by a strict filtration protocol utilizing a 100 mesh wire sieve to guarantee the extraction of flawlessly optimized biomass charcoal. The definitive propellant formulation strictly mandates an exact proportion encompassing 75% potassium nitrate acting as the paramount oxidizer fused with 15% corn cob charcoal alongside 10% sulfur [27] [28] [29] [30] accompanied by an additional 3% dextrin injection calculated from the absolute aggregate mass [31] [32]. The formulation consisting of 75 wt.% potassium nitrate, 15 wt.% carbonaceous material, and 10 wt.% sulfur was selected based on conventional black powder compositions reported in previous combustion studies. Potassium nitrate functions as the oxidizer, while carbon and sulfur serve as fuel components. This formulation was adopted as a baseline composition to facilitate a direct comparison between corn cob charcoal and activated carbon under identical experimental conditions. Every single chemical constituent subsequently undergoes precise quantification upon digital scales before experiencing a mandatory thermal dehydration cycle hitting 50°C spanning exactly 15 minutes to thoroughly obliterate any trace of latent moisture.

The materials were mixed using a ball mill at 60–70 rpm for 1 hour to ensure homogeneity inside a rotary ball mill operating steadily between 60–70 rpm covering an entire 1 hour timespan before the required dextrin binder is finally introduced to prolong the relentless churning procedure for another full 1 hour window. The culminating operational tier demands the careful integration of 70% alcohol reaching exactly 5% of the total concoction weight prior to forcefully extruding the dampened mixture utilizing heavy mechanical press tools shoved into cylindrical molds enduring a sheer pressure of 10 kg/cm^2 followed swiftly by a definitive thermal curing phase inside a $50\text{--}60^\circ\text{C}$ oven lasting exactly 1 hour to successfully birth a pristine operational specimen primed for imminent ballistic testing.

Specimen Testing

The rigorously executed empirical assessments successfully yielded critical quantitative parameters encompassing the precise mass alongside the longitudinal dimension and the exact combustion duration characterizing the scrutinized ballistic propellant specimens. The subsequent mathematical derivation governing the intricate material density [33] [34] [35] is unambiguously demonstrated through the exact algebraic formulation presented within Equation 1:

$$\rho = \frac{m}{V} \quad (1)$$

The variable m undeniably designates the fundamental propellant mass whereas V signifies the spatial volume enclosed within a specific containment vessel assuming a strictly cylindrical geometrical

configuration [36] [37] mirroring the mathematical derivation presented perfectly inside Equation 2:

$$V = \frac{1}{4}\pi d^2 t \quad (2)$$

This aforementioned cylindrical casing possesses an exact diametrical measurement of $d = 0.0185\text{m}$ alongside a definitive longitudinal height reaching $t = 0.06\text{m}$. Deriving the precise burning rate velocity [38] [39] demands the direct application of Equation 3:

$$r = \frac{L}{t_b} \quad (3)$$

wherein L represents the total propellant longitudinal span while t_b acts as the definitive combustion timeframe. This scientific investigation rigorously quantifies kinetic impulse fluctuations across every 10 video frames subsequently converted into standard temporal seconds extracted directly from high-definition visual recordings operating at exactly 60fps utilizing the algebraic formulation governing Equation 4:

$$i = F \Delta t \quad (4)$$

Acquiring the mandatory propulsive thrust metric F alongside its counterpart parameter necessitates the deployment of both Equation 5 and 6:

$$F = W = mg \quad (5)$$

$$t = \frac{\text{frame count}}{\text{frame rate}} \quad (6)$$

wherein F denotes the absolute kinetic force generated by the tested specimen incorporating the measured mass m retrieved from digital scales alongside the standardized planetary gravitational acceleration g sitting firmly at $9.81\text{m}/\text{s}^2$. The subsequent mathematical evaluation ascertaining the specific impulse capability I_{sp} [40] [41] strictly mandates the operational utilization of Equation 7:

$$I_{sp} = \frac{\sum i}{F} \quad (7)$$

A substantially elevated Thrust-to-Weight Ratio fundamentally supercharges the innate ballistic capability of any ascending projectile to aggressively accelerate against an array of hindering external dynamics encompassing planetary gravitational pulls alongside atmospheric frictional resistance and aerodynamic drags or various other counteracting forces disrupting the intended flight trajectory [42] [43] so securing an adequate TWR metric effectively empowers the ascending vehicle to drastically minimize detrimental gravity losses during the rigorous upward orbital climbing phase [43] [44] thereby necessitating the direct application of Equation 8 (8) [44] [45] to flawlessly calculate this exact propulsive parameter:

$$TWR = \frac{\sum F_{thrust}}{F} \quad (8)$$

Research Results

The subsequent comprehensive data arrays meticulously tabulate the exact numerical outcomes retrieved directly from the rigorous empirical assessments detailing the precise physical density parameters alongside the definitive combustion velocity metrics and the ultimate propulsive force capabilities characterizing both the organically derived corn cob propellant and the standardized activated carbon specimens. Scrutinizing these structured tabular representations effectively empowers observers to thoroughly benchmark the operational disparities dividing the agricultural waste derivative against the conventional industrial baseline across multiple critical ballistic thresholds.

Table 1. Density Evaluation Metrics

No	Test Specimen	m PROPELAN					Density Test (ρ)			
		m_0	m'	m BP	L BP	\emptyset BP	V BP	m BP	ρ BP	
		kg	kg	kg	m	m	m ³	kg	kg/m ³	
1	BR-TJ1	0,0197	0,0415	0,0218	0,06	0,0185	0,000016128	0,02175	1348,5736595	
2	BR-TJ2	0,0204	0,0415	0,0211	0,06	0,0185	0,000016128	0,02110	1308,2714582	
3	BR-TJ3	0,0204	0,0407	0,0204	0,06	0,0185	0,000016128	0,02035	1261,7689182	
4	BR-TJ4	0,0202	0,0398	0,0196	0,06	0,0185	0,000016128	0,01960	1215,2663782	
5	BR-TJ5	0,0208	0,0409	0,0201	0,06	0,0185	0,000016128	0,02010	1246,2680715	
6	BR-KA1	0,0206	0,0410	0,0204	0,06	0,0185	0,000016128	0,02035	1261,7689182	
7	BR-KA2	0,0211	0,0411	0,0201	0,06	0,0185	0,000016128	0,02005	1243,1679022	
8	BR-KA3	0,0203	0,0407	0,0204	0,06	0,0185	0,000016128	0,02040	1264,8690875	
9	BR-KA4	0,0207	0,0410	0,0203	0,06	0,0185	0,000016128	0,02030	1258,6687489	

Table 2. Combustion Velocity Evaluation Metrics

NO	Test Specimen	m_0	m'	m Propellant	L Propellant	Burning Time	Burning Rate
		kg	kg	kg	m	s	m/s
1	BR-TJ1	0,01970	0,04145	0,02175	0,06	5,83	0,010299
2	BR-TJ2	0,02035	0,04145	0,02110	0,06	5,91	0,010152
3	BR-TJ3	0,02035	0,04070	0,02035	0,06	6,21	0,009668
4	BR-TJ4	0,02020	0,03980	0,01960	0,06	6,54	0,009169
5	BR-TJ5	0,02080	0,04090	0,02010	0,06	5,99	0,010009
6	BR-KA1	0,02060	0,04095	0,02035	0,06	6,07	0,009885
7	BR-KA2	0,02105	0,04110	0,02005	0,06	5,53	0,010850
8	BR-KA3	0,02030	0,04070	0,02040	0,06	5,91	0,010152
9	BR-KA4	0,02065	0,04095	0,02030	0,06	5,70	0,010528
10	BR-KA5	0,02065	0,04085	0,02020	0,06	6,08	0,009870

Table 3. Propulsive Thrust Evaluation Metrics

NO	Test Specimen	m_0	m'	m Propellant	TWR $\Sigma F_{thrust}/W$	$\Sigma F_{thrust}/\Sigma t$	$\Sigma Impulse$	Isp
		KG	KG	KG	N:N	N/s	Ns	s
1	FT-TJ1	0,08040	0,15350	0,07310	7,04	69,22	40,57	56,58
2	FT-TJ2	0,07715	0,14910	0,07195	7,01	66,98	39,26	55,62
3	FT-TJ3	0,08450	0,15705	0,07255	6,76	68,01	39,86	56,01
4	FT-TJ4	0,08110	0,15325	0,07215	6,95	68,29	40,02	56,55
5	FT-TJ5	0,08965	0,16085	0,07120	6,73	69,40	40,68	58,24
6	FT-KA1	0,08305	0,15595	0,07290	8,42	84,19	49,34	69,00
7	FT-KA2	0,07945	0,14940	0,06995	8,01	76,71	44,96	65,52

8	FT-KA3	0,08505	0,15445	0,06940	8,17	80,90	47,41	69,64
9	FT-KA4	0,07950	0,14955	0,07005	8,57	82,15	48,15	70,07
10	FT-KA5	0,09265	0,16225	0,06960	8,86	92,11	53,99	79,07

Figure 1 illustrates the corn cob charcoal propellant impulse graph. All previously tabulated metrics undergo subsequent mathematical processing to manifest as comparative visual representations showcasing the organic corn cob impulse trajectory within Figure 1 alongside the activated carbon baseline equivalent occupying Figure 2. Scrutinizing both illustrations meticulously reveals the underlying structural characteristics defining each respective substance considering the graphical curve inside Figure 1 demonstrates remarkable stability despite merely achieving a maximum kinetic impulse hitting 49.05 Ns exactly 13 seconds post-ignition. Conversely the propulsive momentum characterizing the activated carbon alternative displays a vastly superior magnitude effortlessly surpassing the 60 Ns threshold across the temporal interval bridging 21 to 24 seconds.

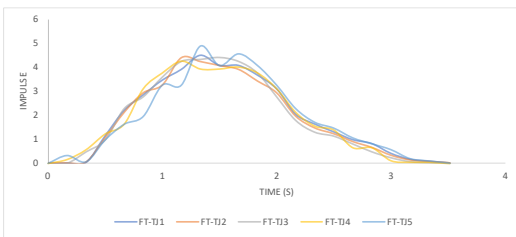


Figure 1. Corn Cob Charcoal Propellant Impuls Chart

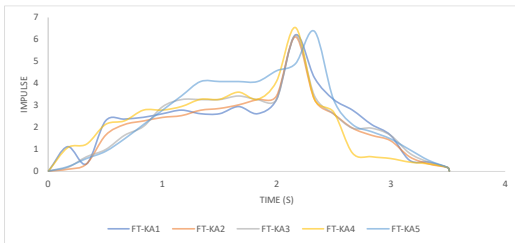


Figure 2. Activated Carbon Propellant Impuls Chart

Figure 3 presents the comparison of specific impulse (Isp) between activated carbon and corn cob charcoal propellants. The activated carbon formulation produced higher specific impulse values ranging from 65.52 to 79.07 s, while the corn cob charcoal propellant generated values between 55.62 and 58.24 s. The average difference of 18.63 s indicates that activated carbon provides better propulsion performance. The higher specific impulse observed in activated carbon may be attributed to its larger surface area and greater combustion efficiency, which promote more effective oxidizer–fuel interactions during combustion. As a result, the combustion process releases energy more efficiently, leading to higher thrust generation and specific impulse values.

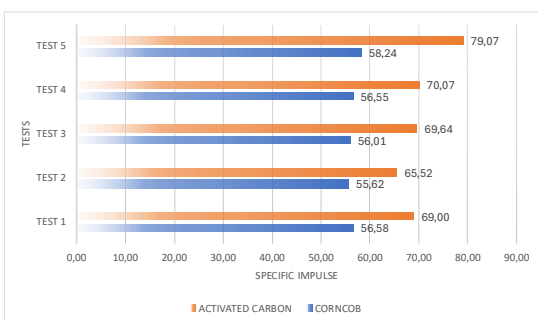


Figure 3. Isp Comparison Chart

In contrast, the corn cob charcoal propellant exhibited lower specific impulse values but demonstrated better consistency among repeated tests, as indicated by its smaller performance deviation. An average performance gap touching exactly 18.63 seconds equaling a 32.5% superiority conclusively proves how the industrial carbon variant facilitates a phenomenally optimal combustion efficiency. Nevertheless Corn cob charcoal exhibited more consistent combustion behavior, as indicated by the smaller variation in specific impulse values among replicate tests characterized by a minuscule maximum deviation reaching a mere 2.62 seconds when pitted directly against the volatile activated carbon rival exhibiting severe performance fluctuations peaking at 13.55 seconds.

Figure 4 perfectly portrays the overarching Thrust-to-Weight Ratio evaluation charting the tested solid composite propellants. Extracting quantitative insights from the visual representation inside Figure 4 distinctly establishes how the activated carbon framework consistently guarantees remarkably superior TWR metrics fluctuating between 8.01–8.86 contrasting sharply against the corn cob alternative stalling around 6.73–7.04 generating an absolute mean discrepancy of 1.83 equaling exactly 23.5%. The absolute peak TWR magnitude

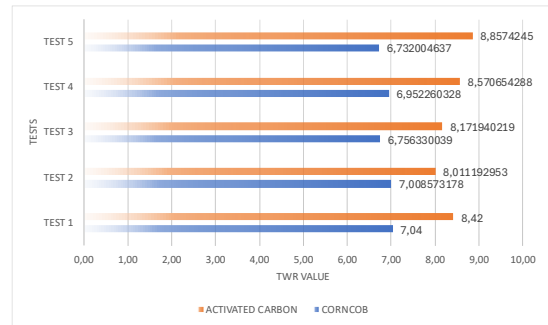


Figure 4. TWR Comparison Chart

characterizing the industrial carbon surfaced flawlessly during Test 5 hitting 8.86 while its most abysmal performance output touching 8.01 during the second trial still manages to easily outclass the ultimate maximum TWR record achieved by the agricultural counterpart resting at 7.04 upon concluding the preliminary test. Despite facing such sheer kinetic inferiority the organic corn cob concoction showcases phenomenal structural stability registering a tremendously narrow inter-sample deviation of simply 0.31 standing in stark opposition to the highly erratic carbon baseline enduring a massive 0.85 variation spread. This profound behavioral dichotomy fundamentally dictates how Activated carbon consistently produced higher thrust-to-weight ratio values than corn cob charcoal whereas the organically harvested corn cob alternative eternally holds the absolute advantage concerning infallible continuous operational consistency.

Conclusion

Analyzing the previously executed specimen evaluations definitively establishes a profound characteristic dichotomy separating the solid composite propellant utilizing activated carbon from the organically derived corn cob charcoal alternative. The standardized activated carbon baseline material demonstrated superior propulsion performance across all evaluated parameters alongside energetic efficiency metrics considering such undeniable superiority is continuously substantiated through phenomenal aggregate propulsive force readings combined with exceptional specific impulse registrations and an extraordinarily elevated thrust-to-weight ratio.

Evaluating the opposing spectrum reveals how the organically sourced agricultural refuse alternative inevitably suffers from a

noticeably inferior kinetic output capability yet this exact botanical derivative unexpectedly showed better combustion stability and repeatability among test specimens paired flawlessly with an extraordinarily unwavering combustion execution observed rigidly across various interchangeable test samples throughout the entire empirical assessment phase. This profound empirical discovery ultimately culminates in a definitive scientific recommendation dictating the mandatory deployment of activated carbon architectures within advanced propulsion mechanisms strictly demanding absolute kinetic power alongside maximum thrust output whereas the corn cob charcoal formulation unequivocally emerges as the most ideal candidate explicitly tailored for rocket frameworks heavily prioritizing unwavering operational stability fused perfectly with completely nonfluctuating burn rates.

References

- [1] B. A. Rizaldi, A. A. B. Perwita, J. Widjayanto, and M. A. Madjid, "Evaluation of Indonesia's Energy Policy Implementation in the Oil Sector to Strengthen National Defense," *J. Pertahanan Media Inf. Tentang Kaji. Dan Strategi Pertahanan Yang Mengedepankan Identity Nasionalism Dan Integr.*, vol. 10, no. 1, pp. 112–123, Apr. 2024, doi: 10.33172/jp.v10i1.19405.
- [2] Q.-H. Vuong, M.-H. Nguyen, and V.-P. La, "The Overlooked Contributors to Climate and Biodiversity Crises: Military Operations and Wars," *Environ. Manage.*, vol. 73, no. 6, pp. 1089–1093, Jun. 2024, doi: 10.1007/s00267-024-01976-4.
- [3] R. J. Pratama, "Dampak Optimasi Pemanfaatan Plts Terhadap Ketahanan Energi Satuan Di Kodam Xii/Tpr," *J. Ketahanan Nas.*, vol. 29, no. 1, p. 1, May 2023, doi: 10.22146/jkn.80314.
- [4] H. F. Airlangga, "TRANSFORMASI ENERGI DI INDONESIA: TANTANGAN DAN PELUANG PENGEMBANGAN ENERGI BARU DAN TERBARUKAN," vol. 5, 2025.
- [5] R. Trialih, BRIN Publishing, and Perhimpunan Pelajar Indonesia, Eds., *Indonesia post-pandemic outlook: environment and technology role for Indonesia development*, First edition. Menteng, Jakarta: BRIN Publishing in cooperation with Overseas Indonesian Students' Association Alliance, 2022.
- [6] R. I. Nugraha, M. I. Shiddieqy, E. B. Laconi, and A. Jayanegara, "Estimation of Rice Straw Adequacy as Ruminants Feed-in Java Based on Yield Area Conversion," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1187, no. 1, p. 012004, May 2023, doi: 10.1088/1755-1315/1187/1/012004.
- [7] E. I. R. Rhofita, "Optimalisasi Sumber Daya Pertanian Indonesia untuk Mendukung Program Ketahanan Pangan dan Energi Nasional," *J. Ketahanan Nas.*, vol. 28, no. 1, p. 82, May 2022, doi: 10.22146/jkn.71642.
- [8] F. N. Barkah, A. O. S. Pratama, and L. D. Lestari, "Optimalisasi Limbah Bonggol Jagung untuk Pangan: Kontribusi terhadap Zero Waste dan Keberlanjutan," *SAKALIMA Pilar Pemberdaya. Masy. Pendidik.*, vol. 2, no. 1, pp. 25–35, Jun. 2025, doi: 10.70211/sakalima.v2i1.204.
- [9] D. Saputra, Y. Erlina, and B. Barbara, "ANALISIS TREND PRODUKSI DAN KONSUMSI JAGUNG PIPILAN DI INDONESIA," *J. SOCIO Econ. Agric.*, vol. 17, no. 1, pp. 30–46, Mar. 2022, doi: 10.52850/jsea.v17i1.4340.
- [10] Y. S. Pramesti, B. Kristanto, and H. Pratama, "Processing of Corn Cobs Waste into Briquettes Using Cob Press Machine Capacity 40 kg / hour," *Procedia Eng. Life Sci.*, vol. 1, no. 1, Mar. 2021, doi: 10.21070/pels.v1i1.852.
- [11] S. Putri, T. Syarif, and A. Aladin, "Blending Batubara Dengan Limbah Biomassa Tongkol Jagung Untuk Mengurangi Ketergantungan Sumber Energi Tidak Terbarukan," *J. Chem. Process Eng.*, vol. 7, no. 2, pp. 117–122, Dec. 2022, doi: 10.33536/jcpe.v7i2.807.
- [12] A. M. Rachma and E. Supriyo, "Pembuatan Briket Arang Dari Kombinasi Bonggol Jagung Dan Tempurung Kelapa Dengan Polyvinyl Acetate (PVAc) sebagai Perekat," *METANA*, vol. 18, no. 2, pp. 93–98, Nov. 2022, doi: 10.14710/metana.v18i2.49325.
- [13] N. Za, L. Maulinda, F. Darma, and M. Meriatna, "PENGARUH KOMPOSISI BRIKET BIOMASSA KULIT JAGUNG TERHADAP KARAKTERISTIK BRIKET," *J. Teknol. Kim. Unimal*, vol. 9, no. 2, pp. 35–42, Feb. 2021, doi: 10.29103/jtku.v9i2.3668.
- [14] F. Goembira, D. M. Aristi, D. Nofriadi, and N. T. Putri, "Analisis Konsentrasi PM2,5, CO, dan CO2, serta Laju Konsumsi Bahan Bakar Biopellet Sekam Padi dan Jerami pada Kompor Biomassa," *J. Ilmu Lingkung.*, vol. 19, no. 2, pp. 201–210, Jun. 2021, doi: 10.14710/jil.19.2.201-210.
- [15] N. L. Nurida, S. Salma, and Jubaedah, "Corn cob biochar as agricultural waste management for increasing soil resilient and crop yield," *E3S Web Conf.*, vol. 467, p. 01003, 2023, doi: 10.1051/e3sconf/202346701003.
- [16] N. A. Dolonseda, "THE STRATEGIC ROLE OF THE DEFENSE INDUSTRY IN THE FRAMEWORK OF RESPONDING TO THE NEED OF KRI WITH C4ISR CAPACITY TO REALIZE MARITIME SECURITY IN THE INDOONESIAN NATIONAL JURISDICTION AREA," *J. Ekon. Bisnis Entrep.*, Oktober 2022.
- [17] B. A. Rizaldi, A. A. B. Perwita, J. Widjayanto, and M. A. Madjid, "Evaluation of Indonesia's Energy Policy Implementation in the Oil Sector to Strengthen National Defense," *J. Pertahanan Media Inf. Tentang Kaji. Dan Strategi Pertahanan Yang Mengedepankan Identity Nasionalism Dan Integr.*, vol. 10, no. 1, pp. 112–123, Apr. 2024, doi: 10.33172/jp.v10i1.19405.
- [18] R. J. Pratama, "Dampak Optimasi Pemanfaatan Plts Terhadap Ketahanan Energi Satuan Di Kodam Xii/Tpr," *J. Ketahanan Nas.*, vol. 29, no. 1, p. 1, May 2023, doi: 10.22146/jkn.80314.
- [19] R. Trialih, BRIN Publishing, and Perhimpunan Pelajar Indonesia, Eds., *Indonesia post-pandemic outlook: environment and technology role for Indonesia development*, First edition. Menteng, Jakarta: BRIN Publishing in cooperation with Overseas Indonesian Students' Association Alliance, 2022.
- [20] A. Susanti, "Pembuatan dan Karakterisasi Biodegradable plastic Berbasis Campuran Pati dan Selulosa Dari Limbah Jagung," *Eksergi*, vol. 18, no. 2, p. 49, Nov. 2021, doi: 10.31315/e.v18i2.5341.
- [21] A. M. Rachma and E. Supriyo, "Pembuatan Briket Arang Dari Kombinasi Bonggol Jagung Dan Tempurung Kelapa Dengan Polyvinyl Acetate (PVAc) sebagai Perekat," *METANA*, vol. 18, no. 2, pp. 93–98, Nov. 2022, doi: 10.14710/metana.v18i2.49325.
- [22] S. Maqsood *et al.*, "Sustainable utilization of corn waste and their role toward the circular economy," *J. Agric. Food Res.*, vol. 23, p. 102165, Oct. 2025, doi: 10.1016/j.jafr.2025.102165.
- [23] Q.-H. Vuong, M.-H. Nguyen, and V.-P. La, "The Overlooked Contributors to Climate and Biodiversity Crises: Military Operations and Wars," *Environ. Manage.*, vol. 73, no. 6, pp. 1089–1093, Jun. 2024, doi: 10.1007/s00267-024-01976-4.
- [24] K. R. Runtu, W. S. Setiani, and M. Utami, "Application Energetic Materials for Solid Composite Propellant to Support Defense Rocket Development," *Int. J. Soc. Sci. Res. Rev.*, vol. 6, no. 1, pp. 153–159, Jan. 2023, doi: 10.47814/ijssr.v6i1.756.
- [25] M. Irfan, S. R. Nidar, Y. Azis, and S. Widianto, "Self-reliant in defense industries: Case study Indonesia," *Cogent Bus. Manag.*, vol. 10, no. 3, p. 2262715, Dec. 2023, doi: 10.1080/23311975.2023.2262715.
- [26] M. E. Junaidi and L. Y. Prakoso, "Pancasila as the Basis for Indonesia's Universal Defense," *J. Soc. Polit. Sci.*, vol. 4, no. 2, Jun. 2021, doi: 10.31014/aior.1991.04.02.283.
- [27] Voennyi Sbornik, "The Last Years of the Black Powder Era," *Voenn. Sb.*, vol. 9, no. 2, Dec. 2021, doi: 10.13187/vs.2021.2.70.
- [28] X. Zhang, Z. Han, C. Wang, Y. Yu, and B. Wu, "Combustion-explosion suppression and environmental protection of typical sulfur-containing hazardous chemicals," *RSC Adv.*, vol. 14, no. 40, pp. 29072–29082, 2024, doi: 10.1039/D4RA05979D.
- [29] T. S. Ritchie, K. E. Riegner, R. J. Seals, C. J. Rogers, and D. E. Riegner, "Evolution of Medieval Gunpowder: Thermodynamic and Combustion Analysis," *ACS Omega*, vol. 6, no. 35, pp. 22848–22856, Sep. 2021, doi: 10.1021/acsomega.1c03380.
- [30] Y. Huang, J. Zhu, C. Hu, H. Mei, Z. Yu, and H. Qin, "Desulfurization of black powder for isotopic profiling using isotope ratio mass spectrometry," *Forensic Sci. Int.*, vol. 337, p. 111379, Aug. 2022, doi: 10.1016/j.forsciint.2022.111379.

- [31] Jobanpreet Singh, "Comparative Analysis of Solid Propellant Rocket Fuel Efficiency: Gunpowder vs. Sorbitol and Potassium Nitrate," *Acceleron Aerosp. J.*, vol. 3, no. 2, pp. 459–463, Aug. 2024, doi: 10.61359/11.2106-2442.
- [32] T. Rotariu *et al.*, "The Influence of Potassium Salts Phase Stabilizers and Binder Matrix on the Properties of Novel Composite Rocket Propellants Based on Ammonium Nitrate," *Materials*, vol. 15, no. 24, p. 8960, Dec. 2022, doi: 10.3390/ma15248960.
- [33] M. R. Mazlan *et al.*, "Comparative Study of Particle Size and Shape Effects on Powder Packing Densities," *J. Kejuruter.*, vol. 36, no. 6, pp. 2563–2570, Nov. 2024, doi: 10.17576/jkukm-2024-36(6)-25.
- [34] J. Mojsilović, J. Petković-Cvetković, J. Nešić, J. Ilić, and M. Krstović, "Research on gas producing time delay pyrotechnic compositions based on black powder and phenol-formaldehyde resin," *Sci. Tech. Rev.*, vol. 73, no. 1, pp. 8–12, 2023, doi: 10.5937/str2301008M.
- [35] C.-Y. Wu, C.-Y. Chang, S.-W. Tsai, S.-C. Lin, T.-C. Hsu, and T.-H. Hsieh, "Activated Carbon for Supercapacitor Electrodes Produced by the Carbonation and Activation of Glucose with Potassium Nitrate," *ACS Appl. Energy Mater.*, vol. 7, no. 16, pp. 6873–6886, Aug. 2024, doi: 10.1021/acsaem.4c00732.
- [36] Y. Wang, Y. Sun, and K. Wu, "Research on the mechanical behavior of the biomass densification process based on a thick-walled cylinder," *BioResources*, vol. 15, no. 3, pp. 4932–4946, May 2020, doi: 10.15376/biores.15.3.4932-4946.
- [37] I. Mawardi *et al.*, "Characteristics of Hybrid Biopellet Based on Oil Palm Wood and Natural Activated Charcoal as a Renewable Alternative Energy Source," *J. Ecol. Eng.*, vol. 24, no. 9, pp. 80–91, Sep. 2023, doi: 10.12911/22998993/168412.
- [38] L. T. DeLuca and A. Annovazzi, "Survey of burning rate measurements in small solid rocket motors," *FirePhysChem*, vol. 4, no. 2, pp. 146–165, Jun. 2024, doi: 10.1016/j.fpc.2023.11.004.
- [39] J. Liu, Y. Wang, X. Li, and J. Cong, "Using the Impulse Method to Determine High-Pressure Dynamic Burning Rate of Solid Propellants," *Aerospace*, vol. 10, no. 9, p. 818, Sep. 2023, doi: 10.3390/aerospace10090818.
- [40] A. Lopez-Telgie, J. O. Murcia Piñeros, and C. Morales-Verdejo, "CHARACTERIZATION OF POTASSIUM NITRATE/DEXTROSE SOLID ROCKET PROPELLANT USING CALORIMETRY," *J. Chil. Chem. Soc.*, vol. 68, no. 1, pp. 5762–5766, 2023, doi: 10.4067/S0717-97072023000105762.
- [41] A. S. Tigga, M. G., and M. V. P.S.N., "Investigation on solid propellant test and time calibration for complete combustion," *E3S Web Conf.*, vol. 391, p. 01097, 2023, doi: 10.1051/e3sconf/202339101097.
- [42] D. S. Aguiar, C. d'Andrade Souto, M. G. D. Silva, and G. D. Silveira, "Study of propellant sloshing with passive mitigation in the stability of a micro-launch vehicle," *Lat. Am. J. Solids Struct.*, vol. 22, no. 6, p. e8427, 2025, doi: 10.1590/1679-7825/e8427.
- [43] S. Stappert, I. Dietlein, J. Wilken, L. Bussler, and M. Sippel, "Options for future European reusable booster stages: evaluation and comparison of VTHL and VTVL return methods," *CEAS Space J.*, vol. 17, no. 1, pp. 155–175, Jan. 2025, doi: 10.1007/s12567-024-00571-x.
- [44] I. S. Grigoriev, A. I. Proskuryakov, and Moscow State University, Baku Branch, Baku, Azerbaijan, "Inserting a Maximum-Mass Spacecraft into a Target Orbit Using a Limited-Thrust Engine with Releasing the Separable Part of Its Launch Vehicle into the Earth's Atmosphere," *Autom. Remote Control*, vol. 85, no. 1, pp. 15–34, Jan. 2024, doi: 10.31857/S0005117924010027.
- [45] H. Ménou, "Hierarchical Emergency Guidance Optimization for reusable Tossback vehicle landing," May 2023.