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A REVIEW OF EXTRATERRESTRIAL ORGANIC CARBON AND ITS POTENTIAL IMPACT OF LIFE ON EARTH

Firza Riyadhini Yarkasih[1)*], Tutut Nurita[1)], Nariyah Al-Zahzamri[1)] dan Riska Ayu Pratiwi[1)]
[1)]Department of Science Education, Faculty of Mathematics and Science, Universitas Negeri Surabaya, Surabaya, Indonesia, 60231
corresponding author:tutunurita@unesa.ac.id

ABSTRAK

Meteorites bombarded the Earth's surface during the early days, early evolution and proliferation of life. It has the potential to provide a source of abiotic organic carbon to support early life. This study aims to analyze research methods used in detecting the use of space organic carbon, analyze research results related to the role of space organic carbon, and provide further understanding to researchers related to organic carbon from space and its potential role and use in human life on earth. This study uses a systematic review method using 15 selected sources from a total of 50 sources of information on national and international news and journal articles related to space organic carbon and its potential. The results of this study showed that extraterrestrial organic carbon produces a source of carbon that is beneficial for microorganisms to integrate into their proteins. By combining inverse stable isotope labeling and infrared spectroscopy, this study shows that organic carbon from Aguas Zarcas carbon chondrite can be harnessed for cell growth. Previous discoveries have also shown that aerobic microbial communities have the potential to be in future human space settlement plans to metabolically access and research carbonaceous asteroid material.
Keywords: *Organic Carbon, Anaerobic Microorganism, Bacterial, Microbial, Earth*

INTRODUCTION

Carbon is an important element as organic material, because most of the dry matter of plants consists of organic material. The carbon element is needed by living creatures as an element that forms biomass in the body and as an energy source whose production process is carried out by organisms that have chlorophyll (the green substance of leaves) (Maulida, et. al, 2016). By using solar energy and through the process of photosynthesis, carbon dioxide gas (CO2) and air absorbed by these organisms are converted into various carbon elements which store energy in the form of algae, bacteria and plant biomass, for example carbohydrates (starch) (Ghafar, et al. , 2018).

Carbon is not only produced within the scope of the earth, but from outer space, carbon can be formed (Maryana, F., et al, 2021). Either by the sun's nuclear reactions, or from existing planets. Extraterrestrial carbon can fall to Earth with the help of large space objects, which are usually called meteors (Tait, et al, 2017). In the process of formation, during the early evolutionary period before the development of life, meteorites bombarded the Earth's surface (Ristasa, 2004). Therefore, the meteorites that have fallen, possess the potential to serve a source of abiotic organic carbon, which is supporting the emergence of life on our planet during its early stages (Osinski, 2020). The intense heat generated by meteorite impact would have led to the pyrolisis of all exciting organic matter (Chyba & Sagan, 1992). This implies that all organic material on the early Earth either formed when the planet cooled or originated ftom extraterrestrial sources such as meteorites (Rojas, et al, 2021).

Meteorites has various types. The type of meteorite related to carbon formation in this topic is carbonaceous chondrite, which is a type of ancient meteorite that is rich in carbon, which has undergone limited changes either through differentiation or heating of the parent object. From this process, it turned out that organic material from the beginning of the Solar System was identified (Aponte, et al, 2020). Organic material contained in carbon chondrites represents organic material delivered by meteorites early in the formation of the Earth (Martins, Z., 2011). Abiotic organic molecules contained in carbonaceous chondrites include amino acids, nucleonase, and organic macromolecules such as polycyclic aromatic hydrocarbons (Martins, Z. et al, 2008).

The studies of previous research conducted by (Mautner, et al, 1997) showed that there was microbial growth in previously carbonaceous meteorite material. The study was conducted under aerobic conditions and utilized extracts from high-temperature meteorites. A subsequent investigation by Waajen (2022) aimed to detect microbial growth in anaerobic conditions on unprocessed carbonaceous meteorites, but it did not reveal any direct utilization of organic carbon from carbonaceous meteorites for biomass synthesis. The potential role of organic material from meteorite carbon still raises pros and cons for previous researchers. By (Xafier, et a., 2021), stated his hypothesis, that the use of meteorite organic material which is continuously used as a substrate for organisms has been neglected because this organic material has heterogeneous properties which will limit its potential as a substrate for the development of life on earth. On the other hand, (Sutherland, 2015), who stated his hypothesis, that the heterotrophic metabolism of proto cells is sustainable, in contrast to the initial autotrophic metabolism, which will release metabolites internally.

Therefore, the main purpose of this review paper was to provide the researchers with the characteristics, findings, and future prospects of extraterrestrial organic carbon and its potential as a substrate for life on earth..

METHODS

The method used in this study is a structured review in the form of systematic literature review (SLR). SLR is a critique and in-depth evaluation of previous research conducted systematically by applying applicable standards (Torgerson, 2003). This method is used to examine the results of research that has been published in journals in a particular field of study. The literature to be identified will be selected using the literature review method. Literature reviews are usually used to draw valid conclusions based on objectively obtained data. The articles we obtain are based on sources google scholar, Publish of Perish, Science direct, and many others. (Kitchenham, 2004), says that structured reviews aim to produce focused, relevant, and specific answers to a problem. This review also investigates the research results of previous researchers, and conducts coherence among research topics related to the existence of research gaps.

In this research process, samples were obtained by searching for and selecting papers that had previously gone through a review process. The articles collected come from authoritative academic sources such as purely scientific publications. Terms such as "Organic Carbon," "Extraterrrestrial Organic Carbon," and "Extraterrrestrial Organic

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Carbon" were used during database searches. Therefore, there will be academic papers on the role of intelligence in protecting personal data and other sensitive information.

Based on the analysis, 15 articles were obtained that fit the space carbon organic keyword format, out of a total of 50 articles. Article selection was carried out using a method consisting of two stages and several levels of literacy, taking into account the above criteria. Specifically, there is a first screening by checking the completeness of the requirements based on the title, abstract, keywords, etc. of the literary source. The second part of the process requires skills in terms of reading and also studying the articles as a whole to ensure that the selected articles are relevant to the overall review objectives. This method is used to find suitable research topics for extraterrestrial organic carbon and its potential for early life on earth, so that it can serve as a guideline for future researchers

RESULT AND DISCUSSION

Life on Earth has the ability to grow and develop using organic carbon resources originating from outside the Earth. The latest theory suggests that similar extraterrestrial organic carbon research may have been the basic ingredient of early life on Earth (Septhon, 2005). Laboratory studies show that microorganisms such as bacteria can use organic carbon compounds found in meteorites and other extraterrestrial materials as a source of energy and nutrients (Keim, 2009). This discovery has an important role for the basic understanding of the existence of life in space. The ability of Earth's microorganisms to use extraterrestrial organic carbon suggests that life may be able to survive and thrive in environments beyond our planet (Lal, 2009). This provides support for the theory that the analysis of microorganisms utilizing extraterrestrial carbon as an energy source highlights the potential existence of life in other Extraterrestrial life, both inside and outside the solar system (Enya, 2022).

Microbial Use of Organic Carbon from Extraterrestrial

Recent research has revealed that isotopic signatures of the carbon present in meteorites have been detected in anaerobic microbial communities (Muhammadali, 2015). Through the results of O-PTIR spectroscopy, Many microorganisms are important for fixing organic carbon because they only contain carbon and therefore protein. Figure 1, The spectrum range is around 1500 to 1760 cm−1. There are other modes related to proteins (called amides I and II, located between 1500–1700 cm−1) and lipids (in the range 1720–1800 cm−1). At temperatures between 1580 and 1700 cm−1, in this mode, amides are converted to carbon present in bacteria, including the carbon isotopes 12C and 13C (Cronin, 1993). In figure 2, the first major component (PC1) distinguishes meaningfully between bacteria grown on carbon 12C from bacteria grown from carbon 13C or without an external carbon source. In this experiment, when bacteria were labeled with 13C at the start of culture, the peak that appeared in Amide I was at 1616 cm−1. This shows that in the Amide I vibration, the carbonyl (C=O) has a 13C label. After the labeled bacteria were transferred to the Aguas Zarcas microcosm, which has a certain type of carbon, there was a change in the position of the Amide I peak. Initially, the peak was located at 1616 cm−1 (which indicates the presence of carbon 13C), but then shifted to 1657 cm−1 (which indicates carbon 12C) after further observation. In Control B, the same peak of 12C carbonyl was observed. Here, 13C-labeled bacteria from an initial culture are transferred to microcosms containing only 12C- with sodium acetate label as the carbon source. Based

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on the main component analysis (PCA), it shows that there is a significant separation between bacteria growing in medium 12C and medium 13C. This separation pattern is mainly base from principal component analysis also showed a clear separation between bacteria growing in 12C medium and 13C medium. The pattern of this separation depends mainly on the peak of Amida I. Additionally, FT-IR technique is used to examine non-biological samples at specific points related to Amide I. FT-IR is also used to evaluate samples that do not come from living organisms. There were no visible peaks of Amide I in the meteorite material or in controls A and B which had minimal presence. This confirms that the amide I peak only appears when microorganisms use carbon from extraterrestrial sources (Waajen, et. al, 2024).

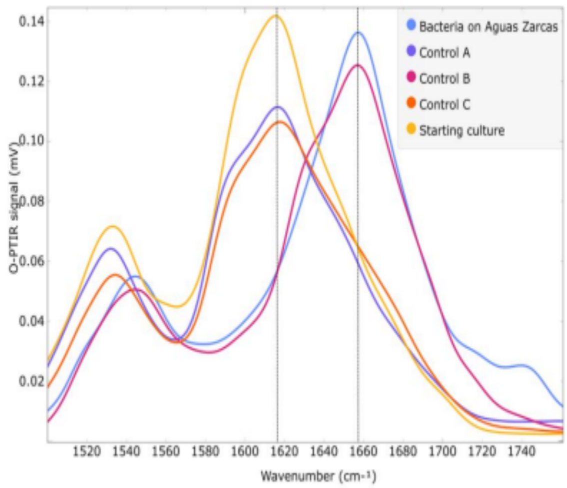

Figure 1. Microbes absorb organic matter from the carbonaceous chondrites of Aguas Zarcas. The O-PTIR spectrum showed that bacteria from the initial culture, Control A (which had been labeled with 13C), and C (without a carbon source) all had an Amide I peak at 1616 cm−1 indicating the presence of 13C carbon, However, bacteria originating from Aguas Zarcas and Control B (unlabeled) showed an Amide I peak at 1657 cm−1, indicating the presence of 12C carbon (Waajen, et. al, 2024).

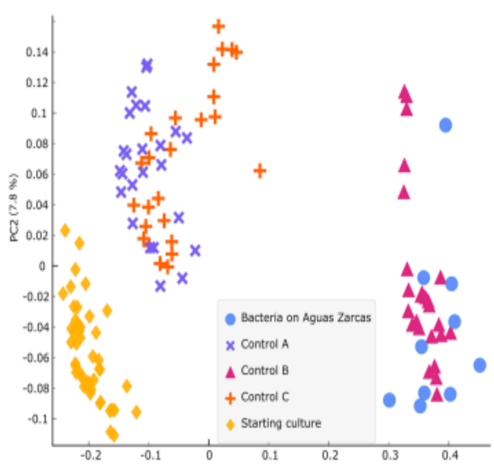

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Figure 2. The differences in bacteria based on the type of carbon isotope they use can be seen through primary analysis of the O-PTIR spectrum in the With a range of 1500 to 1760 cm-1 in biological samples (Waajen, et. al, 2024).

Microbial Growth Uses Organic Carbon from Outside the Earth

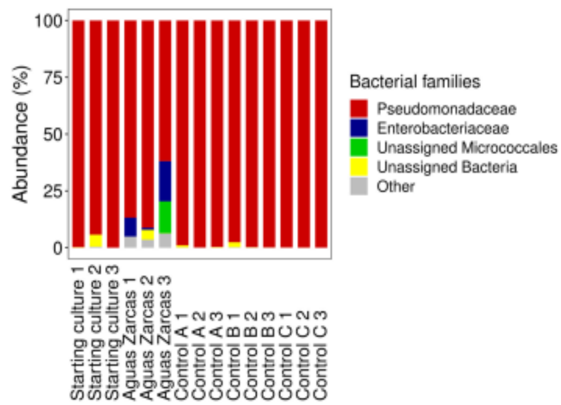

Figure 3. bacteria in a community are observed in various ways. Bacterial growth was observed in the microcosm that already contained Aguas Zarcas, with 3 controls for comparison (Waajen, et. al, 2024).

In figure 3, showed that bacterial growth was slower in samples containing Aguas Zarcas, where this cultivar was dominated by 94%-100% Pseudomonadaceae and the rest were Caulobacteraceae, Carnobacteriaceae, Corynebacteriaceae, and Moraxellaceae. After 14 days, the composition of this community underwent a significant change, not only dominated by Pseudomonadaceae, but various other families were also detected. Among them are Bacillaceae, Beijerinckiaceae, Burkholderiaceae, Carnobacteriaceae, Clostridiales Family XI, Enterobacteriaceae, and Micrococcaceae. However, both controls A, B, and C are all dominated by 98-100% Pseudomonadaceae with other families Burkholderiaceae, Micrococcaceae, and Sphingomonadaceae (Waajen, et. al, 2024).

Based on research from (Waajen, et. al, 2024), microcosmic pH measurements are carried out before and after inoculation, which is for 14 days. In finding significant differences between groups, the researchers used ANOVA analysis and Tukey's post hoc test. Based on the research method, it showed that the microcosm pH with Aguas Zarcas content at the beginning of the experiment and after incubation for 14 days showed higher results than other conditions. In other conditions, the pH of the sample remained stable and showed no change during the experiment. On the other hand, the pH control C showed a significant increase in the form of a change.

Potential Use of Meteorite Organic Carbon in Bacterial Cell Growth

Early in Earth's history, large amounts of space organic matter were sent to the planet's surface in the form of meteorites (Jenniskens, 1998). However, it remains a question as to whether these organic materials could create heterotrophic life (Ghafar, 2018). The heterotrophic theory is principled regarding the origin of life, that organic molecules played an important role for survival and the reproductive system before life began (Delaye, 2005). The study investigated whether or not there was a possibility that space organic matter could have been the source of organic molecules that influenced the early development of heterotrophic biospheres on Earth and other planets after life.

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Research from (Waajen, et. al, 2024) shows that organic carbon from the Aguas Zarcas meteorite plays a role in bacterial cell growth. This stems from the fall of the Aguas Zarcas CM2 meteorite in 2019, which is one of CM2's carbonaceous chondrites that have played an important role since the fall of the Murchison meteorite in 1969. Meteorit Musrchison itself has a high concentration as one of the carbon chondrites containing various compounds essential for life (Sick, 2024). In the Murchison meteorite, research has been carried out using specific carbon isotope analysis in which one of the compounds contained in it is an amino acid. The discovery provides important insights into the mechanism of its formation. Through the results of the study, it was shown that amino acids contained in meteorites can be formed through complex mechanisms, such as Strecker synthesis or reductive amination (Zeichner, 2023). The study combined reverse stable isotope labeling with infrared spectroscopy, which focused on the absorption of 12C or 13C isotopes into bacterial biomass. A change in the vibration of the carbonyl band (C=0) in the amino l protein was obtained, which showed that bacteria labeled 13C (sourced carbon from sodium acetate) underwent a change in the initial culture phase to the peak of amide 12C I in the form of a shift in the peak of amide l 13C from 1616 cm-1 to 1657 cm-1 after growth. In Aguas Zarcas, carbon sequestration (from substrate 12C) from meteorites into bacteria occurs. This indicates an interaction between bacteria and meteorite material. Not only that, the same results were also found in bacteria controlled after growing sourced from sodium acetate labeled 12C. Then, after the growth, the bacteria were moved into a condition without a carbon source on the 13C label and the bacteria retained the 13C label. This shows that the peak of amide l 13C remains stable and no carbon 12C contamination is found that affects the peak shift of amide l. It is also confirmed that the single amide peak l 12 C in samples containing Aguas Zarcas comes from carbon sourced from meteorites (Waajen, et. al, 2024).

Early in Earth's formation, carbonaceous chondrites were shown to provide basic properties for microorganisms, as well as organic materials such as nucleobases, polycyclic aromatic hydrocarbons, and amino acids (Cronin, 1993). Meteorite in this case only accounts for as much as 3.8% of the total meteorites that have fallen to Earth. The existence of meteorites is very meaningful in understanding the process of recycling water and even organic matter on the surface region of planets in the solar system that contain various chemical ingredients of extraterrestrial origin (Kerraouch, 2022). In addition to water and other minerals, the organic matter present in carbon chondrites is also likely to be a concentrated solution that plays a role in early life. In research (Schulte, 2014), states that the increase in biodiversity can be due to the presence of extraterrestrial carbon and other nutrients, so that it can support heterotrophic growth. Thus, in this case, it supports the theory, that the organic matter contained in carbon chondrites has provided a concentrated solution that can be utilized in the early phases of life (Brenner, 2005).

The discovery (Pizzarello, 2020) states that the carbon meteorite Aguas Zarcas has a small amount of water-soluble nitrate. In meteorites, carbon has organic compounds that are difficult to decompose, where decomposition is usually done by Pseudomonas bacteria. Microorganisms on earth in the past and present may have had primes, but there must be similarities (Jousset, 2013). For example, the presence of Aguas Zarcas plays a role in supporting the growth of various bacterial families not identified in the early culture phase, such as Bacillaceae, Beijerinckiaceae, Clostridiales Family XI, Enterobacteriaceae, and Steroidobacteraceae. Pseudomonas' expertise in decomposing

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organic compounds is due to its ability to perform arginine deiminase anaeorobically. However, it is thought that the families of Pseudomonas had very few numbers in early life. This result due to the microcosm lacks much biomass, resulting in a low inoculum that is less detectable by the system, which is usually only represented by the presence of microbial communities (Waajen, et. al, 2024).

Based on analysis of the results of previous studies, microbes have been shown to be able to absorb carbon from Aguas Zarcas. However, microbial population growth tended to be slower than microbial growth in control experiments. This is due to the influence of pH and different geochemical and ionic conditions. pH affects microbial growth. The pH of the microcosm contained by Aguas Zarcas itself tends to be higher than the pH of other microcosms. Then the geochemical and ionic conditions in the microcosm itself were caused because Aguas Zarcas created a condition that was probably less favorable than the control experiment. One proof is through the release of materials / ions that dissolve in air sourced from silicate matrix (Tunney, 2011). Although Aguas Zarcas is considered one of the purest carbonaceous chondrites, based on the analysis we conducted, some of the previous researchers through meteorite fragments showed that Aguas Zarcas had been contaminated by organic molecules from Earth. This is a natural phenomenon that can occur with any space object exposed to the atmosphere or surface of the Earth. Despite indications of organic contamination from Earth at Aguas Zarcas, the total amount of contaminated carbon chondrites is only 1% of tital (Garvie, 2021). Research by [36] has researched and categorized the contaminants they found into 5 groups, including fuels, pesticides, agricultural products, plastic dna, and others not biodegradable. Therefore, these microorganisms would prefer to consume mcontaminants from the earth and avoid carbon meteorites later. Any meteorite that falls to Earth is potentially contaminated (Yulianti, 2005). So to eliminate contamination, further experiments are needed using new materials collected from carbon asteorid.

The results of previous research have important implications for our insight into the possibility of extraterrestrial life and how sustainable use of extraterrestrial resources is for human life on it. The results show that microbes can use organic carbon from meteorites for cell growth, refuting previous researchers' assumptions that organic matter is incapable and too heterogeneous for microbial growth. Some meteorites were found to contain various organic molecules. It was formed more than 4.6 billion years ago and has never been exposed to life on Earth (Schmitt, 2010). Meteorites create ideal cognition for microbial colonization by being affected by cracking and porotity in meteorites as well as weathering of the outer crust that occurs over time as a result of external fusion. In addition to creating ideal conditions for microbes, meteorites can be ideal microenvironments for studying primary succession. Micrometeorites have much more abundant populations than meteorites. This is because they have the same geochemical composition and are likely to accumulate in heavy mineral fractures in angim modified sediments (Tomkins, 2019). The discovery suggests that heterotrophic growth driven by space carbon could have been an important energy source early in the formation of Earth and other planets (Arif, 2023).

CONCLUSION

Based on several reviewed literature, it can be concluded that Earth microorganisms are capable of utilizing organic carbon compounds originating from

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outside Earth as a source of energy and nutrition. Microorganisms can consume and convert organic carbon from extraterrestrial sources, especially meteorites, into materials that can be used for cell growth. Bacterial growth in media containing carbon from meteorites indicates a shift in bacterial community composition, as well as slower growth compared to control media. The growth rate of bacteria suggests the potential use of meteoritic carbon by microbes. The result of O – PTIR and FT – IR spectroscopic analysis indicate the absorption of carbon from meteoroids by microbes. Microbes can use organic carbon from meteorites as an energy source, which may have implications for the possibility of life beyond Earth, as life – supporting resources have been identified outside the planet, such as the use of microbial communities to convert carbonaceous asteroid material into useful raw materials. Thus, this article provides a strong foundation for further exploration of the use of extraterrestrial resources in efforts to explore and create humas sustainability in space.

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REFERENCES

Aponte, J. C. et al. (2020). Extraterrestrial organic compounds and cyanide in the CM2 carbonaceous chondrites Aguas Zarcas and Murchison. Meteorit. Planet Sci. 55, 1509–1524.

Arif, Ahmad. (2023). Bennu Asteroid Samples Contain Water and Carbon which are Important for Life. Accessed May, 5, 2024, https://shorturl.asia/OZSRD

Brenner, D. J., Krieg, N. R., & Staley, G. M. (n.d.). Bergey's Manual of Systematic Bacteriology, Volume Two, Part B: Te Gammaproteobacteria. Bergey's Manual of Systematic Bacteriology vol. 2 (Springer, 2005): Vol. Volume Two (Part B). Springer.

Chyba, C. & Sagan, C. (1992). Endogenous production, exogenous delivery and impact-shock synthesis of organic molecules: An inventory for the origins of life. Nature 355, 125–132.

Cronin, J. R., & Chang, S. (1993). Organic Matter in Meteorites: Molecular and Isotopic Analyses of the Murchison Meteorite. The Chemistry of Life's Origins, 209–258.

Delaye, L., & Lazcano, A. (2005). Prebiological evolution and the physics of the origin of life. Physics of Life Review, 2(1), 47–64.

Enya, K., Yoshimura, Y., Kobayashi, K., Yamagishi, A., 2022. Extraterrestrial Life Signature Detection Microscopy: Search and Analysis of Cells and Organics on

Mars and Other Solar System Bodies. Space Sci. Rev. 218. https://doi.org/10.1007/s11214-022-00920-4

Garvie, L. A. J. (2021). Mineralogy of the 2019 Aguas Zarcas (CM2) carbonaceous chondrite meteorite fall. American Mineralogist, 106(12), 1900–1916.

Ghafar, M., et al. (2018). Kandungan Karbon Tanah Di Kawasan Hutan Sekunder Pegunungan Deudap Pulo Aceh Kabupaten Aceh Besar. Prosiding Seminar Nasional Biotik, 274-280.

Handayanto, E., Hairiah, K. (2007). Biologi Tanah, Landasan Pengelolaan Tanah Sehat. Malang: Pustaka Adipura.

Jennniskens, P., Wilson, M. A., Packan, D., Laux, C. O., Kruger, C. H., Boyd, L. D., Popova, O. P., & Fonda, M. (1998). Meteors: A Delivery Mechanism of Organic Matter to the Early Earth. Earth, Moon, and Planets, 82, 57–70.

Jousset, A., Bienhold, C., Chatzinotas, A., Gallien, L., Gobet, A., Kurm, V., Küsel, K., Rillig, M. C., Rivett, D. W., Salles, J. F., Van Der Heijden, M. G. A., Youssef, N. H., Zhang, X., Wei, Z., & Hol, G. W. H. (2017). Where less may be more: How the rare biosphere pulls ecosystems strings. In ISME Journal (Vol. 11, Issue 4, pp. 853–862). Nature Publishing Group. https://doi.org/10.1038/ismej.2016.174.

Keim NL, Griffen SC, Bremer AA, Graham JL. (2009). Consuming fructose-sweetened, not glucose-sweetened, beverages increases visceral adiposity and lipids and decreases insulin sensitivity in overweight/obese humans. J Clin Invest.119(5):1322-34

Kerraouch, I., Kebukawa, Y., Bischoff, A., Zolensky, M., Wolfer, E., Hellman, J., Ito, M., King, A., & Trieloff, M. (2022). Heterogeneous nature of the carbonaceous chondrite breccia Aguas Zarcas–Cosmochemical characterization and origin of new carbonaceous chondrite lithologies. Geochimia et Cosmochimica Acta, 334, 155–186.

Lal, R. (2009). The potential for soil carbon sequestration. In Agriculture and climate change: An agenda for negotiation in Copenhagen. (Brief 5). Focus 16.

Martins, Z. (2011). Organic chemistry of carbonaceous meteorites. Elements 7, 35–40.

Martins, Z. et al. (2008). Extraterrestrial nucleobases in the Murchison meteorite. Earth Planet Sci. Lett. 270, 130–136.

Maryana, F. O. T., dkk. (2021). Ilmu Pengetahuan Alam Untuk SMP Kelas VIII. Jakarta: Pusat Perbukuan, dalam https://buku.kemdikbud.go.id/katalog/ilmu-pengetahuan-alam-untuksmp-kelas-viii diakses 5 Mei 2024.

Maulida, et al. (2016). Stok Karbon Pohon Di Kawasan Hutan Sekunder Rinon Pulo Breuh Kabupaten Aceh Besar. Prosiding Seminar Nasional Biotik, 81-84.

Mautner, M. N., Conner, A. J., Killham, K. & Deamer, D. W. (1997). Biological potential of extraterrestrial materials: 2. Microbial and plant responses to nutrients in the murchison carbonaceous meteorite. Icarus 129, 245–253.

Muhamadali, H., Chisanga, M., Subaihi, A., & Goodacre, R. (2015). Combining Raman and FT-IR Spectroscopy with Quantitative Isotopic Labeling for Differentiation of E. coli Cells at Community and Single Cell Levels. Analytical Chemistry, 87, 4578–4586.

Osinski, G. R., Cockell, C. S., Pontefract, A. & Sapers, H. M. (2020). Te role of meteorite impacts in the origin of life. Astrobiology 20, 1121–1149.

Pizzarello, S., Yames, C., & Cooper, G. (2020). The Aguas Zarcas (CM2) meteorite: New insights into early solar system organic chemistry. Meteoritics & Planetary Science, 55(7).

Ristasa, R. A. (2004). Sejarah Perkembangan Teori Evolusi Makhluk Hidup. PEBI4204/MODUL 1, 1.2-1.76.

Rojas, J. et al. (2021). Te micrometeorite fux at Dome C (Antarctica), monitoring the accretion of extraterrestrial dust on Earth. Earth Planet Sci. Lett. 560, 116794.

Schmitt, K. P., Gabelica, Z., Gougeon, R. D., Fekete, R. D., Kanawati, B., & Harir, M. (2010). High molecular diversity of extraterrestrial organic matter in Murchison meteorite revealed 40 years after its fall. Proceedings of the National Academy of Sciences, 107, 2763–2768.

Schulte, R.P.O, Creamer, R.E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C. and O'Uallachain, D. (2014). Functional land management: A framework for managing soilbased ecosystem services for the sustainable intensification of agriculture. Environmental Science and Policy Journal 38: 45-58.

Sephton, M. A. (2005). Organic matter in carbonaceous meteorites: past, present and future research. Philos Trans A Math Phys Eng Sci., 2729(42).

Sick, Volker. (2024). How does carbon capture benefit the Earth? We mapped out those who gain and lose because of this practice. Accessed May, 5, 2024, https://shorturl.asia/MU37V

Sutherland, J. D. (2015). Te origin of life-out of the blue. Angew. Chem. Int. Edition 55, 104–121.

Tait, A. W., Gagen, E. J., Wilson, S. A., Tomkins, A. G. & Southam, G. (2017). Microbial populations of stony meteorites: Substrate controls on frst colonizers. Front. Microbiol. 8, 1227.

Tomkins, A. G., Genge, M. J., Tait, A. W., Alkemade, S. L., Langendam, A. D., & Perry, P. P. (2019). High survivability of micrometeorites on Mars: sites with enhanced availability of limiting nutrients. Journal of Geophysical Research, Planet, 124, 1802–1818.

Tunney, L. D., Hill, P., Herd, C., Hillts, R. W., & Holt, M. (2011). Distinguishing between terrestrial and extraterrestrial organic compounds in the CM2 Aguas Zarcas carbonaceous chondrite: Implications for intrinsic organic matter. Meteoritics & Planetary Science, 1948–1972.

Waajen, A. C., Lima, C., Goordacre, R., & Cockell, C. S. (2021). Life on Earth can grow on extraterrestrial organic carbon. Scientific Reports, 14(3692).

Waajen, A. C., Prescott, R. & Cockell, C. S. (2022). Meteorites: benefcial or toxic for life on Early Earth? Growth of an anaerobic microbial community on a carbonaceous chondrite. Access Microbiol 4, po0297.

Waajen, A., et al. (2024). Life on Earth Can Grow on Extraterrestrial Organic Carbon. Nature Scientific Reports, 14: 3691, DOI: https://doi.org/10.1038/s41598-024-54195-6.

Xavier, J. C. et al. Te metabolic network of the last bacterial common ancestor. (2021). Commun. Biol. 4, 413.

Yulianti, H., Akhadi, M. (2005). Radionuklida Kosmogenik Untuk Penanggalan. Buletin Alara, 6(3), 163-171.

Zeichner, S.S., Chimiak, L., Elsila, J.E., Sessions, A.L., Dworkin, J.P., Aponte, J.C., Eiler, J.M., 2023. Position-specific carbon isotopes of Murchison amino acids elucidate

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extraterrestrial abiotic organic synthesis networks. Geochim. Cosmochim. Acta 355, 210–221. https://doi.org/10.1016/j.gca.2023.06.010