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

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Abstract

The universe is a space containing large amounts of both organic and inorganic carbon that has the potential to encourage heterotrophs on habitable planets. Meteorites are materials that can transport carbon from outer space to the planet's surface. Meteorites bombarded the Earth's surface during the early days of evolution and proliferation of life, potentially providing 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 the researchers associated with organic carbon from space and its potential in human life on Earth. This study uses a systematic review method using 15 sources of information from national and international news and journal articles related to space organic carbon and its potential. This study showed that extraterrestrial organic carbon produces a source of carbon that is beneficial for microorganisms to integrate into their proteins. Combining inverse stable isotope labeling and infrared spectroscopy 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 potential in human space settlement plans to access and research carbonaceous asteroid material.

INTRODUCTION

Carbon is an essential element of organic material because most of the dry matter of plants consists of organic material. Carbon is needed by living creatures as an element that forms biomass in their bodies and as an energy source produced by organisms with chlorophyll (the green substance in leaves) [1]. By using solar energy and through photosynthesis, carbon dioxide (CO2) and air absorbed by these organisms are converted into various carbon elements, which store energy in the form of plant biomass, such as carbohydrates (starch) [2].

Carbon is not only produced within the scope of the Earth, but from outer space, carbon can be formed [3]. It can originate from the sun's nuclear reactions or existing planets. Extraterrestrial carbon can fall to Earth with the help of large space objects, usually called meteors [4]. During the early evolutionary period before the development of life, meteorites bombarded the Earth's surface [5]. These meteorites have the potential to serve as a source of abiotic organic carbon, supporting the emergence of life on our planet during its early stages [6]. The intense heat generated by meteorite impacts would have led to the pyrolysis of all existing organic matter [7]. This implies that all organic material on early Earth formed when the planet cooled or originated from extraterrestrial sources such as meteorites [8].

Meteorites come in various types. In this context, the kind of meteorite related to carbon formation is carbonaceous chondrite, an ancient meteorite rich in carbon that has undergone limited changes through differentiation or heating of the parent object [9]. This process identified organic material from the early Solar System [10]. Organic material contained in carbon chondrites represents organic material delivered by meteorites early in Earth's formation [11]. Abiotic organic molecules in carbonaceous chondrites include amino acids, nucleobases, and organic macromolecules such as polycyclic aromatic hydrocarbons [12].

Previous studiesPrevious research studies by [13], showed 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 [14] aimed to detect microbial growth in anaerobic conditions on unprocessed carbonaceous meteorites. Still, 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 [15] 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, [16] 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 primary purpose of this review paper was to provide the researchers with the characteristics, findings, and prospects of extraterrestrial organic carbon and its potential as a substrate for life on Earth.

RESEARCH METHODS

This study employs a structured review in the form of a systematic literature review (SLR). SLR involves a critical and in-depth evaluation of previous research conducted systematically by applying applicable standards [17]. This method examines research results published in journals within a particular field. The identified literature is selected using a literature review method, typically used to draw valid conclusions based on objectively obtained data. The articles received for this review were sourced from Google Scholar, Publish or Perish, ScienceDirect, and other academic databases [18], Structured reviews aim to produce focused, relevant, and specific answers to a problem. This review also investigates the research results of previous studies and examines coherence among research topics related to the existence of research gaps.

In the research process, samples were obtained by searching for and selecting papers that had undergone review. The articles collected come from authoritative academic sources, such as scientific publications. Terms such as "Organic Carbon," "Extraterrestrial Organic Carbon," and "Extraterrestrial Organic Carbon" were used during database searches. This search resulted in 15 articles fitting the criteria out of 40 articles. The article selection process involved two stages and several levels of scrutiny, considering the criteria above. The first screening involved checking the requirements' completeness based on the literary sources' title, abstract, keywords, etc., The second part required skills in reading and analyzing the articles to ensure that the selected articles were relevant to the overall review objectives. This method is used to identify suitable research topics related to extraterrestrial organic carbon and its potential for early life on Earth, providing guidelines for future researchers.

RESULTS AND DISCUSSION

Life on Earth can 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 essential ingredient of early life on Earth [19]. 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 [20]. This discovery has a vital role in 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 [21]. This supports 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 [22].

1. Microbial Use of Organic Carbon from Extraterrestrial

Recent research has revealed that isotopic carbon signatures in meteorites have been detected in anaerobic microbial communities [23]. According to the results of O-PTIR spectroscopy, many microorganisms are essential for fixing organic carbon because they only contain carbon and protein. Figure 1, The spectrum range is around 1500 to 1760 cm−1. Other modes are 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 [24]. In this experiment, when bacteria were labeled with 13C at the start of culture, the peak in Amide I was at 1616 cm−1. This shows that the carbonyl (C=O) has a 13C label in the Amide I vibration. After the labeled bacteria were transferred to the Aguas Zarcas microcosm, which has a specific 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 labeled as the carbon source. The principal component analysis (PCA) shows a significant separation between bacteria growing in medium 12 c and medium 13 c. This separation pattern is mainly based on Principal component analysis (PCA), which also showed a clear separation between bacteria growing in 12 C medium and 13 C medium. The pattern of this separation depends mainly on the peak of Amida I.

Additionally, the FT-IR technique is used to examine non-biological samples at specific points related to Amide I and to evaluate samples that do not come from living organisms. There were no visible peaks of Amide I in the meteorite material or controls A and B, which had minimal presence. This confirms that the amide I peak only appears when microorganisms use carbon from extraterrestrial sources [25].

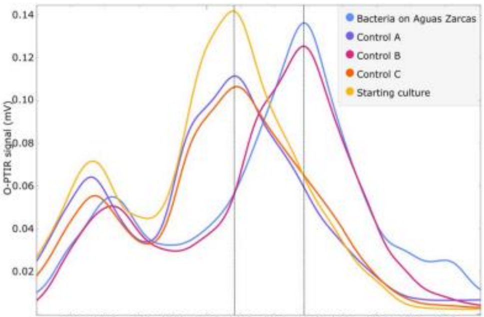

Figure 1. Microbes absorb organic matter from the carbonaceous chondrites of Aguas Zarcas. The O-PTIR spectrum showed that bacteria from the initial culture, Control A (labeled with 13C), and C (without a carbon source) had an Amide I peak at 1616 cm−1, indicating the presence of 13C carbon. However, bacteria originating from Aguas Zarcas and Control B (unlabeled) showed an Amide I peak at 1657 cm−1, indicating the presence of 12C carbon [25].

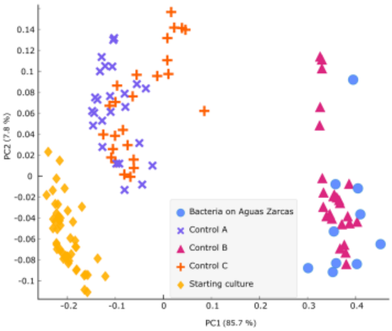

Figure 2. The differences in bacteria based on the type of carbon isotope they use can be seen through primary analysis of the O-PTIR spectrum in the range of 1500 to 1760 cm-1 in biological samples. The first significant component (PC1) distinguishes meaningfully between bacteria grown on carbon 12C from bacteria grown on carbon 13C or without an external carbon source [25].

2. Microbial growth uses organic carbon from outside the Earth

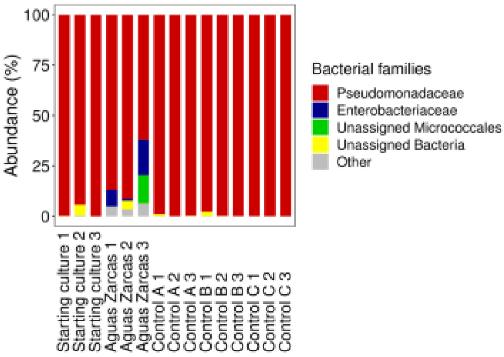

Figure 3. Bacteria in a community are observed in various ways. Bacterial growth was observed in the microcosm containing Aguas Zarcas, with three controls for comparison [25].

The results showed that bacterial growth was slower in samples containing Aguas Zarcas, where 94%-100% Pseudomonadaceae and the rest dominated this cultivar were Caulobacteraceae, Carnobacteriaceae, Corynebacteriaceae, and Moraxellaceae. After 14 days, the composition of this community underwent a significant change; not only was it dominated by Pseudomonadaceae, but various other families were also detected. Bacillaceae, Beijerinckiaceae, Burkholderiaceae, Carnobacteriaceae, Clostridiales Family XI, Enterobacteriaceae, and Micrococcaceae. However, controls A, B, and C are all dominated by 98-100% Pseudomonadaceae with other families, Burkholderiaceae, Micrococcaceae, and Sphingomonadaceae [25].

Based on research from [25], microcosmic pH measurements are carried out before and after injection for 14 days. The researchers used ANOVA analysis and Tukey's post hoc test to find significant differences between groups. 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.

3. 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 as meteorites [26]. However, whether these organic materials could create heterotrophic life [27]. The heterotrophic theory is principled regarding the origin of life, that organic molecules played an essential role in survival and the reproductive system before life began [28]. The study investigated whether or not space organic matter could have been the source of organic molecules that influenced the early development of heterotrophic biospheres on Earth and other planets' afterlife.

Research from [25] 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, one of CM2's carbonaceous chondrites that have played an essential role since the fall of the Murchison meteorite in 1969. Meteorit Murchison has a high concentration as a carbon chondrite containing various compounds necessary for life [29]. In the Murchison meteorite, research has been carried out using specific carbon isotope analysis in which one of its compounds is an amino acid. The discovery provides essential insights into the mechanism of its formation. The study results showed that amino acids contained in meteorites can be formed through complex mechanisms, such as Strecker synthesis or reductive amination [30]. 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) changed 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. 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 [25].

Early in Earth's formation, carbonaceous chondrites were shown to provide basic properties for microorganisms and organic materials such as nucleobases, polycyclic aromatic hydrocarbons, and amino acids [24]. In this case, meteorites only account for as much as 3.8% of the total meteorites that have fallen to Earth. The existence of meteorites is significant 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 [31]. In addition to water and other minerals, the organic matter in carbon chondrites is also likely to be a concentrated solution that plays a role in early life. Research [32], states that the increase in biodiversity can be due to extraterrestrial carbon and other nutrients, which can support heterotrophic growth. Thus, this case 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 [33].

The discovery [34] 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, whereas Pseudomonas bacteria usually do decomposition. In the past and present, microorganisms on Earth may have had primes, but there must be similarities [35]. 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 organic compounds is due to its ability to perform arginine deiminase anaerobically. However, it is thought that the families of Pseudomonas had very few numbers in early life. This result is due to the microcosm lacking 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 [25].

Based on analysis of previous studies' results, microbes can 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 that of other microcosms. Then, the geochemical and ionic conditions in the microcosm were caused by Aguas Zarcas, who created a condition that was probably less favorable than the control experiment. One proof is releasing materials/ions that dissolve in the air from a silicate matrix [36]. Although Aguas Zarcas is considered one of the purest carbonaceous chondrites, based on our analysis, some of the previous researchers, through meteorite fragments, showed that organic molecules from Earth had contaminated Aguas Zarcas. 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% [37]. Research by [36] has categorized the contaminants into five groups: fuels, pesticides, agricultural products, plastic DNA, and others not biodegradable. Therefore, these microorganisms would prefer to consume pollutants from the earth and avoid carbon meteorites later. Any meteorite that falls to Earth is potentially contaminated [38]. So, to eliminate contamination, further experiments are needed using new materials collected from carbon asteroids.

The results of previous research have important implications for our insight into the possibility of extraterrestrial life and how sustainable the use of extraterrestrial resources is for human life. 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 [39]. Meteorites create ideal cognition for microbial colonization by being affected by cracking and porosity 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. They have the same geochemical composition and are likely to accumulate in heavy mineral fractures in angim-modified sediments [40]. 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 [41].

CONCLUSIONS

The evidence reviewed in this article indicates that organic carbon from extraterrestrial sources can serve as a resource for life on Earth. Microbial communities have been shown to thrive on organic matter delivered by meteorites, and laboratory studies support the potential of these compounds to contribute to early life processes. However, much is still to be understood about the specific mechanisms by which extraterrestrial organic matter is incorporated into terrestrial ecosystems. Further research is necessary to elucidate these processes and their implications for understanding life's origins and the potential for life elsewhere in the universe.

The study of organic carbon from extraterrestrial sources offers valuable insights into life's resilience and adaptability. This research enhances our understanding of early Earth conditions and expands the possibilities for life beyond our planet. Future studies should focus on the detailed biochemical pathways and the potential for similar processes on other celestial bodies.

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