Isovaline

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summary

Isovaline, also known as 2-amino-2-methylbutyric acid, is a branched-chain non-standard amino acid with the molecular formula C5H11NO2 and a molecular weight of 117.15 g/mol. It is an isomer of valine, differing in the position of a methyl group, which classifies it as a non-polar, aliphatic amino acid. Isovaline is notable for its unique structural properties, which allow it to serve as a valuable building block in organic synthesis and pharmaceuticals, enhancing the stability and solubility of various compounds.[1][2][3]

Biologically, isovaline plays an essential role in protein synthesis and can influence the stability and functionality of polypeptides. Its incorporation into proteins may affect their interactions and overall biochemical properties. Additionally, isovaline has been implicated in plant and microbial interactions, enhancing nutrient availability and promoting growth within agricultural ecosystems, showcasing its potential importance in both environmental and agricultural applications.[4][5][6]

The synthesis of isovaline can be achieved through methods such as the Strecker synthesis and catalytic hydrogenation, and it has garnered attention due to its possible extraterrestrial origins, found in meteorites, which raises intriguing questions regarding the origins of life on Earth.[7][8] Moreover, isovaline's applications extend to medical uses, particularly in pain management, and its derivatives are explored for enhancing crop yields, underscoring its multifaceted relevance in both health and industry.[5][8][9]

Despite its benefits, the safety of isovaline, particularly in animal nutrition, has been evaluated and found to be acceptable, with studies indicating no significant toxic effects.[10][11] However, ongoing research is necessary to fully understand its nutritional implications and potential health impacts, especially in the context of dietary requirements and functional foods.[12] As such, isovaline remains a subject of significant interest across various scientific and industrial fields.

Chemical Properties

Isovaline is a branched-chain amino acid with the molecular formula C5H11NO2 and a molecular weight of 117.15 g/mol[1][13]. It is an isomer of the more common amino acid valine, distinguished by the position of a methyl group, which is shifted from position 3 to position 2 in isovaline[2]. This structural variation classifies isovaline as a non-polar, aliphatic amino acid due to its branched-chain structure, which incorporates an isopropyl group[14][15].

In terms of its chemical structure, isovaline consists of an alpha-amino group (-NH3+), an alpha-carboxyl group (-COO), and a hydrophobic side chain, which contributes to its properties and functions in biological systems[2]. The compound appears as a white to off-white solid at room temperature[16].

Isovaline's unique properties make it of interest in various applications, including pharmaceuticals and organic synthesis. As a building block in the synthesis of complex molecules, isovaline and its derivatives can enhance certain chemical properties, such as stability and solubility, making them valuable in drug design and material science[3]. Its distinct structural characteristics also allow it to be incorporated into peptides and proteins where standard amino acids might not be suitable, offering alternative pathways for biochemical reactions[3].

Biological Role

Isovaline, a non-standard amino acid, plays a significant role in various biological processes. As a derivative of valine, it shares similar biochemical properties and contributes to protein synthesis. The introduction of isovaline into polypeptide chains

can affect protein structure and function due to its unique side chain configuration, which differs from that of standard amino acids[4].

Protein Synthesis and Function

The incorporation of isovaline into proteins can lead to the formation of polypeptides that exhibit altered physical and chemical properties. This modification can influence protein stability, folding, and interactions with other biomolecules, thereby affecting the overall functionality of proteins within biological systems[4]. Furthermore, isovaline may participate in metabolic pathways where it acts as a substrate or product, thus contributing to cellular processes such as energy production and the biosynthesis of other essential compounds[17].

Role in Plant and Microbial Interactions

Isovaline, along with other non-standard amino acids, has been identified as a potential factor in the interactions between plants and beneficial microbes. These interactions can enhance nutrient availability and promote plant growth, demonstrating the importance of amino acid derivatives in agricultural applications and ecosystem dynamics[5]. In particular, isovaline's structural properties may enable it to serve as a signaling molecule or as part of a broader set of metabolic interactions in plants and soil microorganisms, facilitating better nutrient utilization and stress responses[6].

Implications in Health and Nutrition

From a nutritional perspective, the role of isovaline is still being explored, particularly concerning its potential benefits or impacts on human health. As protein sources become more diverse, understanding the functions of amino acids like isovaline may provide insights into dietary requirements and the development of functional foods that leverage specific amino acid profiles for health benefits[12]. Additionally, research into amino acid metabolism highlights the necessity of isovaline and its derivatives in growth and developmental processes, particularly in contexts such as childhood nutrition, where amino acid availability is critical for proper development[-12].

Synthesis

Isovaline, also known as 2-amino-2-methylbutyric acid, can be synthesized through various chemical methods. One notable approach is the Strecker synthesis, where aldehydes react with ammonia and hydrogen cyanide, followed by hydrolysis to yield amino acids, including isovaline[3]. Additionally, catalytic hydrogenation of ±keto acids represents another viable method for synthesizing isovaline[3].

Multiple synthetic routes exist for the production of isovaline, including stereospecific methods designed to yield high purity and specific isomer forms[18]. The Breslow group has notably reported progress in developing artificial transamination reactions that could enhance the efficiency of these syntheses[19].

Furthermore, the synthesis of isovaline is not limited to terrestrial methods. The discovery of isovaline in the Murchison meteorite, which fell to Earth in 1969, suggests that it may have an extraterrestrial origin[7][2]. This has led to hypotheses that enantioenriched extraterrestrial compounds like isovaline could have played a role in the emergence of biological homochirality on early Earth, a fundamental characteristic of life[8]. As such, isovaline not only serves as a valuable chemical compound but also as a topic of interest in discussions about the origins of life and prebiotic chemistry.

Applications

Medical Uses

Isovaline has garnered attention for its potential applications in the treatment of various pain syndromes. Specifically, it is considered for use in managing acute and chronic pain, particularly in cases where conventional therapies exhibit limited efficacy or unacceptable toxicity[5]. Chronic pain, often associated with conditions such as neuropathies and fibromyalgia, can be particularly challenging to treat due to its complex nature and varied underlying causes. Research indicates that isovaline may help alleviate pain associated with both peripheral and central nervous system disorders, including post-operative pain, neuropathic pain, and pain from traumatic injuries[5][3].

Agricultural Applications

In addition to its medical potential, isovaline and its derivatives are explored for agricultural uses. They can be incorporated into various application methods such as seed treatments, in-furrow with starter fertilizers, and foliar applications during different growth stages of crops[8]. The flexibility of application makes isovaline a valuable asset in enhancing crop yields while potentially reducing reliance on synthetic fertilizers[8]. This agricultural application is supported by findings that emphasize the importance of a robust agronomic base, which includes appropriate seed choices and soil management practices[5].

Biochemical Research

Isovaline also plays a role in biochemical research, particularly in studies related to prebiotic chemistry and the origins of biological homochirality on early Earth. The presence of enantioenriched extraterrestrial compounds like isovaline may have contributed to the development of essential biochemical processes, suggesting a connection between extraterrestrial chemistry and the origins of life[8]. Furthermore, the exploration of isovaline's non-natural derivatives holds promise for advancements in pharmaceuticals and biotechnology[3].

Economic Significance

Isovaline, an amino acid variant, plays a significant role in various economic sectors, particularly in specialty chemicals and animal nutrition. The production and demand for isovaline are closely linked to broader trends in the global economy, especially as they pertain to health, nutrition, and resource efficiency[20].

Market Dynamics

The market for amino acids, including isovaline, has seen notable growth, driven by increased demand in pharmaceuticals and animal feed. Key players such as BASF, Evonik Industries, and CJ CheilJedang are actively involved in this market, providing various amino acids for multiple applications. The global amino acid market has been experiencing shifts due to supply chain dynamics, including freight costs that significantly affect pricing and availability of these essential compounds[21][22][23].

Industry Impact

The animal feed sector is a primary consumer of isovaline and related amino acids, which are critical in enhancing the health and productivity of livestock. The growing pet population and the rising demand for quality pet food further stimulate the market for feed-grade amino acids, including isovaline. As consumer preferences shift towards high-quality nutrition, the economic significance of isovaline in promoting animal health becomes increasingly pronounced[9][23].

Sustainability and Innovation

The production of isovaline is also aligned with sustainability initiatives within the agro-industrial sector. As the industry seeks to optimize resource usage and reduce environmental impact, the integration of amino acids like isovaline into feed formulations is becoming more common. This aligns with the United Nations' Sustainable Development Goals, particularly regarding sustainable industrialization and innovation within food systems[24][23]. By supporting efficient food production processes, isovaline contributes not only to economic growth but also to the sustainability of agricultural practices globally.

Safety and Toxicology

The safety of isovaline, particularly its use in animal nutrition, has been evaluated and found to be acceptable for consumers and the environment. Research indicates that l-valine produced using various strains of E. coli, such as CCTCC M2020321 and CGMCC 22721, demonstrates a similar safety profile, ensuring that its application does not pose significant risks to animal health or ecological systems[10][25].

In toxicological assessments, studies involving mice have shown no significant differences in behavior or central nervous system effects when comparing control saline with isovaline formulations[11]. Specifically, compounds tested did not produce central nervous system toxicity or noticeable behavioral disturbances in the subjects, indicating a favorable safety profile[11].

Moreover, regulatory standards for the production and handling of isovaline emphasize the importance of maintaining high safety and quality standards. For instance, comprehensive safety data sheets (SDS) and certificates of analysis (COA) are provided to ensure that handlers are well-informed about the safe storage, handling, and disposal of the product[26][27].

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