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REVIEW ARTICLE

Glucosamine: Production and applications

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ABSTRACT

Glucosamine, an essential amino monosaccharide derived from chitinous biomass, serves as a primary substrate for the synthesis of glycosaminoglycan chains in human cartilage. While naturally occurring in the body, its commercial production primarily involves the chemical or enzymatic degradation of shellfish waste. This review evaluates the efficacy of its four prevalent forms; glucosamine, glucosamine hydrochloride, glucosamine sulphate, and N-acetyl glucosamine with a focus on their therapeutic mechanisms. Specifically, glucosamine derivatives manage osteoarthritis and rheumatoid arthritis by promoting cartilage repair and exerting potent anti-inflammatory effects, while also showing promise in treating cardiovascular, neurological, and dermatological conditions. Despite its $3.5 billion global market value, industrial production faces significant feasibility challenges, including the high cost of enzymatic processes and the environmental impact of chemical deacetylation waste. Furthermore, while generally recognized as a safe dietary supplement by the USFDA, clinical application must account for potential allergenic reactions in individuals with shellfish sensitivities and monitor long-term toxicological profiles to ensure patient safety.

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Introduction

Carbohydrates, represented by the chemical formula $C_n(H_2O)_n$, are the predominant organic molecules in living beings. Carbohydrates, also referred as saccharides, participate in numerous biological activities. They function as the primary source and storage type of energy, as well as structural components. Monosaccharides, the fundamental units of carbohydrates (e.g., glucose), function as the primary energy

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source for metabolism and are utilized in biosynthesis (Chen et al., 2010).

Glucosamine is an amino monosaccharide, having a molecular weight of 179.17 Da, found naturally in articular cartilage, and serves as a substrate for the synthesis of glycosaminoglycan chains. It is glucose where a hydroxyl group on the second carbon atom substitutes an amino group (Jamialahmadi, 2019). First glucosamine (2-amino-2-deoxy-D-glucose) was synthesised in 1876 by a German scientist Dr. Georg Ledderhose, who hydrolysed chitin with strong hydrochloric acid (Roseman, 2001).

The body's demand for glucosamine is met through standard cellular glucose metabolism. It serves as the principal precursor for the production of diverse complex molecules in cartilage and other fluid matrices that facilitate the lubrication of cartilaginous joints within joint cavities. Glucosamine is present in several tissues and secretions and serves as a crucial primary substrate for the synthesis of hyaluronic acid, a component of synovial fluid vital for collagen formation. It also serves as a substrate for the synthesis of aggrecan and proteoglycan, which confer hydrophilization against cartilage and are later employed in the treatment of osteoarthritis (Reginster et al., 2012; Karaduman et al., 2013; Öztürk et al., 2013; Sibi et al., 2013; Fawwaz et al., 2018).

Glucosamine is formulated in 4 forms: Glucosamine, glucosamine-sulphate, glucosamine-hydrochloride and N-acetylglucosamine (Maley, 1956; Yüksel, 2008; Wanichpongpan & Attasat, 2016), of which chemical structures are displayed in Figure 1.

Glucosamine-sulphate (the sulphate salt of D-glucosamine) is the most widely available formulation in commercial preparations and the one most frequently included in clinical trials. D-glucosamine, the active component, readily traverses biological membranes and shows particular affinity for cartilage tissue containing proteoglycans. Some studies indicate that glucosamine sulphate is superior to other formulations, while other studies suggest that glucosamine sulphate and glucosamine hydrochloride are equally effective. There is still no consensus on this matter (Eraslan, 2010). On the other hand, glucosamine sulphate has been reported to have a safer profile, as it does not suppress prostaglandin synthesis like nonsteroidal anti-inflammatory drugs (Karaduman et al., 2013). It is also the most commonly used form in medical studies in Thailand (Wanichpongpan & Attasat, 2016).

Glucosamine hydrochloride can be produced by high-intensity acid or enzymatic hydrolysis. This form of glucosamine lacks sulphate and is 99% pure (Xavier, 2006; Fox & Stephens, 2007; Benavente et al., 2015).

N-Acetylglucosamine, also known as 2-acetamino-2-deoxy-β-D-glucose or 2-(acetylamino)-2-deoxy-D-glucose, is a monosaccharide derivative of glucose that is extensively utilized globally. This amino monosaccharide's chemical formula is $C_8H_{15}NO_6$, having a molecular weight of 221.21 Da. N-Acetylglucosamine is often a white, mildly sweet powder that has a melting point of 221°C (Chen et al., 2010).

To prepare this review, a comprehensive literature search was conducted using major scientific databases, including Web of Science, Scopus, PubMed, ScienceDirect, and Google Scholar. Searches were performed using combinations of the keywords glucosamine, N-acetylglucosamine, glucosamine hydrochloride, glucosamine sulphate, chitin, chitosan, shellfish waste, glucosamine extraction, enzymatic hydrolysis, microbial production, biotechnology, and nutraceutical applications. Studies were selected based on their relevance to glucosamine sources, extraction and production technologies, physicochemical properties, biomedical applications, and industrial significance. Duplicate publications, conference abstracts lacking sufficient methodological detail, and studies not directly related to glucosamine production or applications were excluded from consideration.

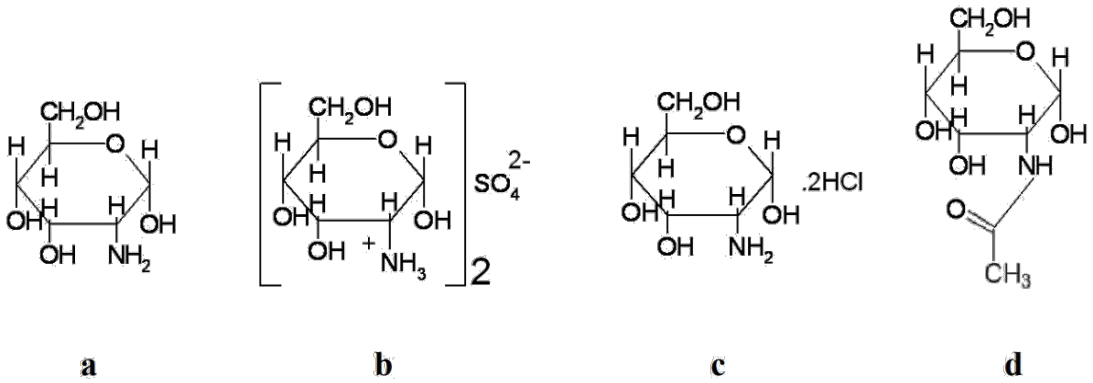


Figure 1. Glucosamine and its derivatives' chemical structures (a: Glucosamine; b: Glucosamine-Sulphate; c: Glucosamine-Hydrochloride; d: N-acetylglucosamine)

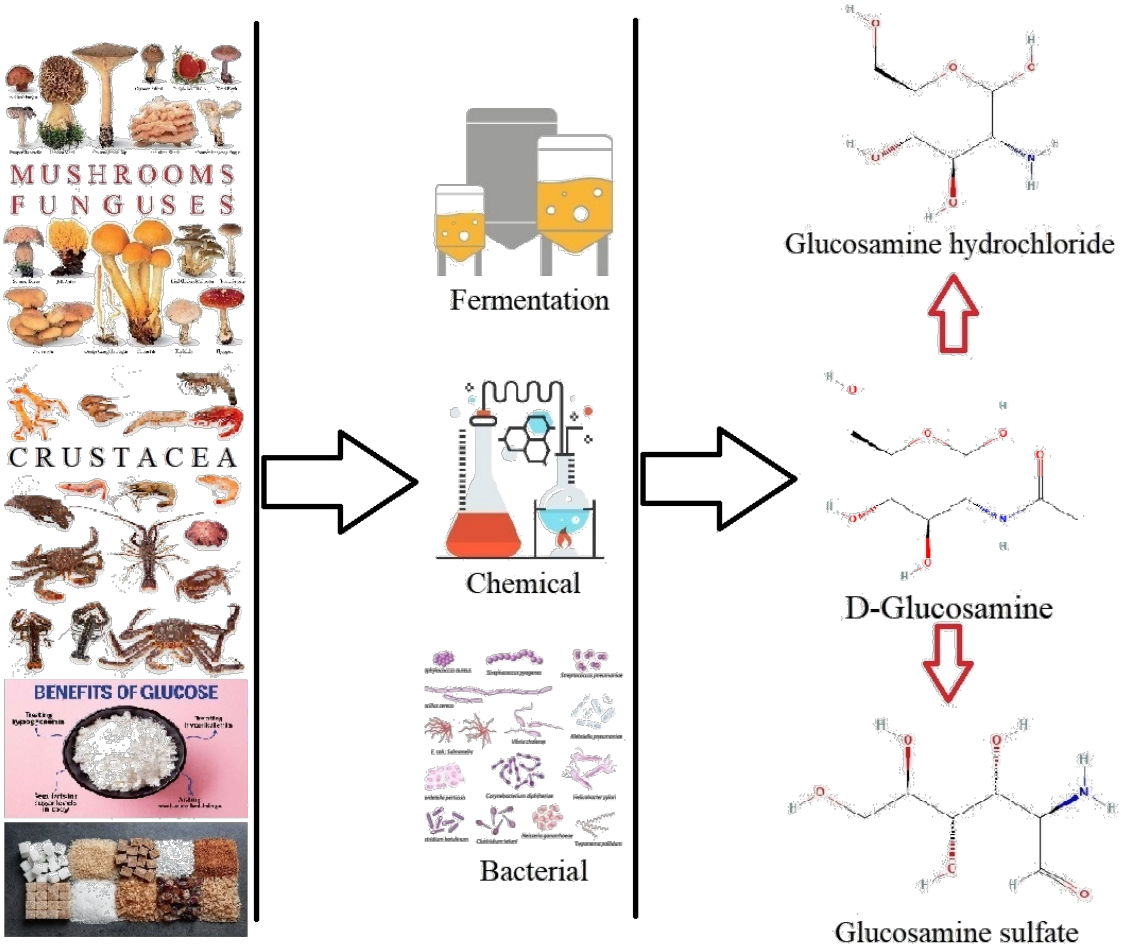


Figure 2. Glucosamine extraction methods

Extraction of Glucosamine

Glucosamine is an amino monosaccharide synthesised in the body from glucose via the hexosamine pathway. It is naturally present in connective tissues, helping maintain strength, flexibility, and elasticity. Glucosamine serves as a precursor in the synthesis of synovial fluid, mucous membranes and cartilage.

Glucosamine occurs naturally in the human body, shellfish waste as part of chitin and chitosan structures, animal bones and bone marrow. Besides animal sources, glucosamine is also produced from plant sources, including corn, wheat and mushrooms. Industrially, it is most commonly produced from chitin and chitosan in the shells of marine organisms such as oysters, lobsters, crabs and shrimps (Hespel et al., 2006; Yüksel, 2008; Eraslan, 2010; Küçükgülmez et al., 2012; Benavente et al., 2015; Kadak et al., 2023) (Figure 2).

Chitin is the second most prevalent natural polymer following cellulose and is a component of the structural material in fungal cell walls, insect exoskeletons, and crustacean shells (Kadak, 2023). Chitin consists of 2-acetamido-2-deoxy-β-D-glucose (N-acetylglucosamine) (Chang et al., 1997).

Glucosamine can be synthesised from shellfish waste using several methods, including deproteinization, demineralisation, decolourisation, and subsequent hydrolysis, with hydrogen ions or enzymes acting as catalysts to convert the chitin macromolecular chain into N-acetylglucosamine monomers. The structure and function of chitin resemble those of cellulose; however, the hydroxyl group (-OH) at C-2 in cellulose is substituted with an acetamide group (-$NHCOCH_3$). Chitosan is a product of chitin (Sabır et al., 2017; Kadak, 2017; Küçükgülmez, 2018).

Chitosan, which is produced through deacetylation of chitin in alkaline conditions and by conversion of acetylamino groups to amino groups (NH_2), consists of 2-amino-2-deoxy-β (glucosamine). It is an important and interesting biomaterial in the pharmaceutical and medical fields due to its non-toxicity, non-allergenicity, non-irritation, biodegradability, and bio permeability. Chitin and its derivative chitosan possess diverse applications across several sectors, including paper technology, textile, fibre, pharmaceutical and biomedical, cosmetics, food

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and beverage, drinking water and wastewater treatment and agriculture (Shahidi & Synowiecki, 1991; Healy et al., 2003; Coward-Kelly et al., 2006; Duarte De Holanda & Netto, 2006; Seo, 2006; Kucukgulmez et al., 2011; Sibi et al., 2013; Benavente et al., 2015; Kadak & Çelik, 2015; Sabır et al., 2017; Farivar et al., 2022). D-glucosamine can be synthesised by hydrolysing chitosan (Figure 3) (Wanichpongpan & Attasat, 2016).

Glucosamine can be obtained by acid hydrolysis with strong mineral acids or by enzymatic hydrolysis with bacterial chitinase. Different techniques have been investigated for the production of glucosamine hydrochloride (G-HCl) from chitin by acid hydrolysis. Leite et al. (2002) treated the sample with 37% hydrochloric acid (1:5 S/L ratio) at 100°C for various reaction times using a reflux technique to hydrolyse the sample. Novikov (2004) carried out acid hydrolysis of chitin and chitosan using 36.5% HCl at 50°C and 70°C. Li et al. (2007) conducted experiments to optimise the preparation of G-HCl by rising the ambient temperature from 60°C to 90°C (Benavente et al., 2015; Ma & Gao, 2019).

The synthesis of glucosamine hydrochloride from chitin involves a straightforward hydrolysis procedure. In this reaction, chitin undergoes deacetylation and depolymerisation to yield glucosamine hydrochloride in the presence of hydrochloric acid (Wahyuni 2015). The literature reports the enzymatic hydrolysis of chitin to produce N-acetyl D-glucosamine. Stryer (1995) described the reaction mechanism for the acid hydrolysis of the N-acetyl bond. The literature extensively details that chitin hydrolysis in a concentrated acid solution yields acetic acid and D-glucosamine salt, while chitosan hydrolysis produces D-glucosamine salt (Islam et al., 2011). Extraction methods of glucosamine obtained from different sources are presented in Table 1.

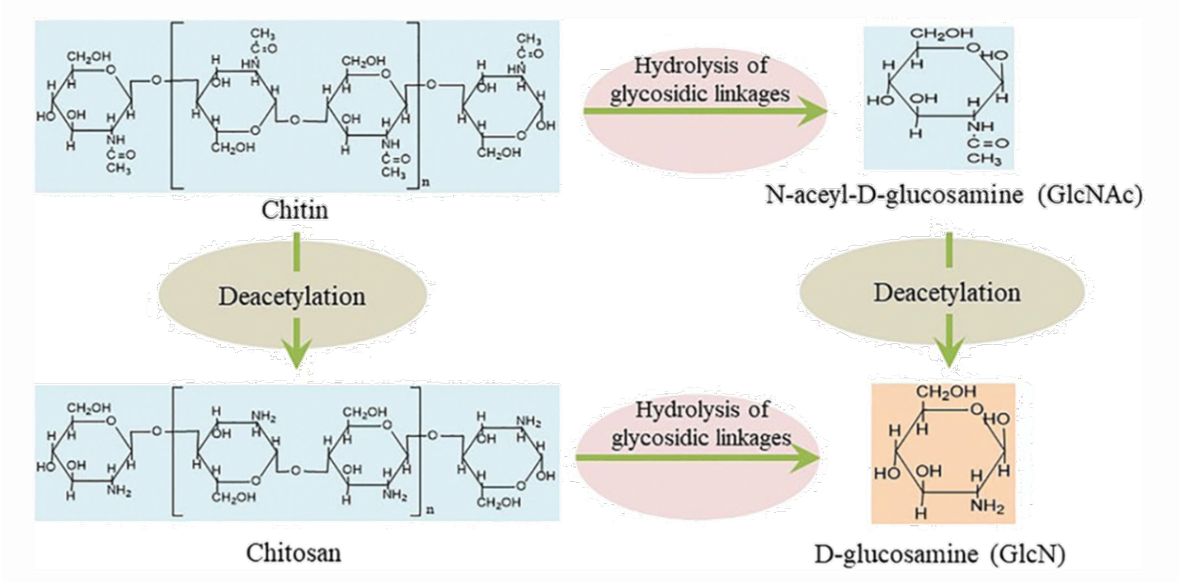


Figure 3. Glucosamine extraction from chitin and chitosan

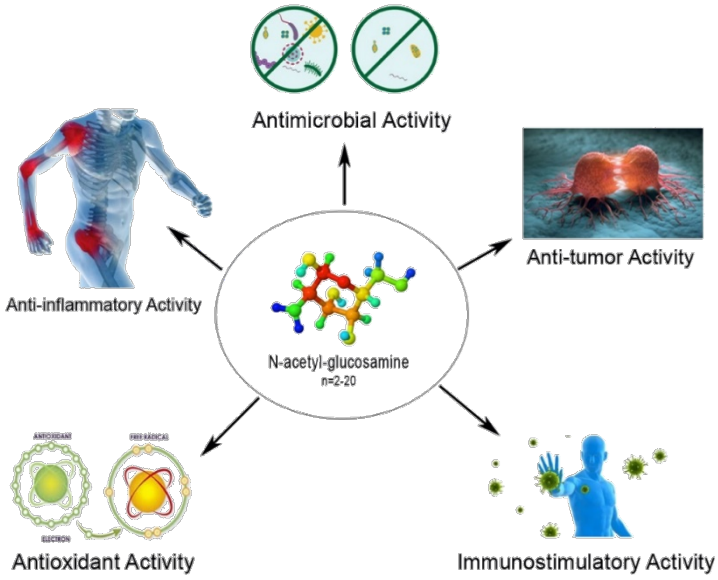


Figure 4. Activities of glucosamine in the body

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Table 1. Extraction methods of glucosamine obtained from different sources

Source	Product	Method	References
Shellfish	Glucosamine hydrochloride (Glu-HCl)	Shrimp and crab shells were used to produce glucosamine. Shells were demineralised with 0.5 M HCl for 8 h at room temperature, deproteinized with 1N NaOH for 2 h at 90°C, and deacetylated with 2N NaOH for 8 h at room temperature. The produced chitosan material was washed with HCl for 75 min at 90°C, during which Glu-HCl was produced.	Sibi et al. (2013)
Mushroom (*Schizophyllum commune, Pleurotus ostreatus*)	N-acetylglucosamine	Local Sri Lankan mushrooms were used to extract chitosan. Dried and ground mushrooms were demineralised using 1 M HCl and 1 M NaOH for deproteinization for 24 h. To remove pigments, NaOCl was used for bleaching. The deacetylation process was done with 40% NaOH. At the end of the process, the chitosan material is hydrolysed with HCl to break 1-4 β-glycosidic bonds and yield glucosamine.	Kalutharage & Rathnasinghe (2020)
Seafood waste	Glucosamine hydrochloride, N-acetylglucosamine	This review comprehensively examines glucosamine production from crustacean shells, fungal biomass, and microbial systems. It compares acid hydrolysis, enzymatic conversion, and microbial fermentation for producing glucosamine, glucosamine hydrochloride, and N-acetylglucosamine, emphasizing sustainability, process optimization, and future industrial applications.	Protity & Zhou (2025)
Shrimp shell	Glucosamine hydrochloride	Persian Gulf shrimp were used for chitin extraction. The second step of this research involved extracting chitin, which was then hydrolysed with hydrochloric acid solutions. The researcher declared that the best hydrolysis process was 30-37% HCl solutions at a 9:1 (v/w) acid-to-solid ratio for 4 h reaction times to obtain an optimum yield and the characteristic properties of glucosamine hydrochloride.	Mojarrad et al. (2007)
Shrimp (*Litopenaeus vannamei*) shell	Glucosamine hydrochloride, Glucosamine sulphate	The researcher used high-deacetylated commercial shrimp chitosan. They synthesise glucosamine hydrochloride and glucosamine sulphate using this chitosan. Chitosan was hydrolysed with hydrochloric acid (3:1 hydrolysis ratio) at 80°C for 6h, and with sodium sulphate (1:2.5 ratio) at 40°C for 30min for maximum yield.	Wanichpongpan & Attasat (2016)
Langostino crab	N-acetylglucosamine, Glucosamine	A combination of enzyme preparations from *Trichoderma atroviride* and *Serratia marcescens* was used for the enzymatic production of N-acetyl-glucosamine from langostino crab shells. Non-pretreated shells were mixed with cultured microorganisms and incubated for 12 days at 32°C.	Donzelli et al. (2003)
Chitin	N-acetyl-D-Glucosamine	The enzymatic reaction with crude chitinase obtained from *Trichoderma sp. G* (CHITG) and *Bacillus sp. W* (CHIBW) were used on chitin. In this experiment, researchers used an optimal hydrolase ratio of chitinase: chitin of 1 mU/mg, a substrate concentration of 30 mg/mL, pH 4.0 and 9.0, and temperatures of 40°C and 50°C for 8-day reaction periods.	Kudan et al., 2010
Shrimp shells (*Penaeus monodon*)	N-acetylglucosamine	In this study, shrimp shells were processed to isolate chitin, which was subsequently hydrolyzed enzymatically using *Mucor circinelloides* chitinase. The optimized fermentation conditions produced N-acetylglucosamine, illustrating the feasibility of fungal enzyme-assisted conversion as an alternative to conventional acid hydrolysis.	Halim et al. (2020)
Crab shell and squid	N-Acetyl-D-Glucosamine, D-Glucosamine	Two different sources of chitin, crab and squid pen, were used as substrates for digestion by bacterial chitinases obtained from *Burkholderia cepacia* (TU09) and *Bacillus licheniformis* (SK-1). The experimental reaction consisted of a 100 mU/mL enzyme ratio, pH 6.0, and controlled hydrolysation reaction conditions were 10–40 mg/mL of the substrate at 37-50°C in a shaking water bath for 6-7 days, respectively.	Pichyangkura et al. (2002)
Crab shell	N-acetylglucosamine	Commercial chitin and chitosan from crab shells were treated with illumination using white linearly polarised light (WLPL) to stimulate chitinase and chitosanase. Chitin and chitosan were suspended in 0.1M pH 5.5 acetate buffer at 85-90°C for 15 min, and then 1.4mL of the enzyme solution was added to the solutions, which were incubated at a 37°C-water bath for 0-100 min.	Konieczna-Molenda et al. (2008)
Shrimp	N-acetylglucosamine (GlcNAc)	The authors used untreated shrimp shell powder as the substrate and applied a metagenome-derived β-N-acetylglucosaminidase enzyme cocktail. The process directly converted seafood waste into N-acetylglucosamine (GlcNAc) without acid pretreatment, demonstrating an environmentally friendly extraction strategy with high product purity.	Zhou, et al. (2024)

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Applications of Glucosamine

Glucosamine is the amino monosaccharide precursor of the disaccharide component of glycosaminoglycans, which serve as the fundamental building blocks of proteoglycans, the primary material of articular cartilage. It is a constituent of proteoglycans in cartilage, skin, and connective tissue, and has recently attracted significant interest for its therapeutic potential in osteoarthritis, being marketed as a nutritional supplement. The activities of glucosamine in the body are presented in Figure 4.

Glucosamine derivatives were hypothesised 30 years ago to play a role in reducing symptomatic manifestations of osteoarthritis due to their high concentrations in joints. Subsequently, many studies have been conducted on this topic and glucosamine derivatives have been widely utilized in the amelioration of osteoarthritis symptoms (Müller-Faßbender et al., 1994; Noack et al., 1994; Barclay et al., 1998; Qiu et al., 1998; Houpt et al., 1999; Delafuente, 2000; Rindone et al., 2000; Reginster et al., 2001; Matheson & Perry, 2003; Richy et al., 2003; Liew, 2004; Towheed et al, 2005; Mroz & Silbert, 2004; Bruyere & Reginster, 2007; Messier et al., 2007; Vlad et al., 2007; Dahmer & Schiller, 2008; Huskisson, 2008; Kirkham & Samarasinghe, 2009; Naito et al., 2010; Chiusaroli et al., 2011; Islam et al, 2011; Reginster et al., 2012; Henrotin et al., 2012; Karaduman et al., 2013; Qian et al., 2013; Henrotin et al., 2014; Kucharz et al., 2016; Ogata et al., 2018; Fernandez-Martin et al., 2021). Glucosamine predominantly resides in cartilage and takes a crucial part in maintaining cartilage flexibility and facilitating joint lubrication. The human body produces glucosamine by merging glucose with the amino acid glutamine. It is commonly used to relieve the symptoms of osteoarthritis (Delafuente, 2000). Glucosamine formulations for arthritis are available as the hydrochloride salt or glucosamine sulphate, and are frequently combined with chondroitin sulphate. Hanson et al. (1997) and Lippiello et al. (2000) reported that chondroitin sulphate, together with glucosamine, showed a synergistic effect in increasing glycosaminoglycan synthesis in cartilage cells. Fox & Stephens (2007) observed that a combination of glucosamine and chondroitin sulphate mitigated clinical symptoms in osteoarthritis.

In the United States, it is one of the most widely used natural products, other than vitamins and minerals, used by adults as supplementary or alternative medicine. It is the most popular food additive (Islam et al., 2011).

In randomised-placebo-controlled studies, glucosamine use was reported to prolong exercise time and reduce pain (Öztürk et al., 2013). Furthermore, glucosamine has been documented to possess anti-inflammatory, antimicrobial, and anti-cancer properties (Sibi et al., 2013).

In vitro researches have shown that glucosamine sulphate reduces prostaglandin E2 (pGE2) production and inhibits DNA-binding nuclear factor kappa B (NFkB) in chondrocytes and synovial cells. In some studies, on the mechanism, higher concentrations of glucosamine were found in human plasma and synovial cells in patients with a glucosamine intake of 1500 mg per day than in human plasma and synovial cells (20%). As glucosamine affects both anabolic and catabolic genes, it has been suggested that the therapeutic effects of glucosamine may be due to catabolic activities rather than anabolic effects. Glucosamine sulphate has been reported to be a more potent inhibitor of gene expression than glucosamine hydrochloride (Kozakçıoğlu, 2009).

Glucosamine sulphate also decreases the activity of cartilage-damaging enzymes such as collagenase and phospholipase A2, the activity of lysosomal enzymes and the formation of superoxide radicals. On the other hand, glucosamine sulphate has a safer profile as it does not suppress prostaglandin synthesis, unlike nonsteroidal anti-inflammatory drugs (Karaduman et al., 2013).

Many clinical investigations have shown that glucosamine sulphate is effective in controlling osteoarthritis, not only in terms of symptoms but also in delaying its progression (Chiusaroli et al., 2011).

Although glucosamine has been extensively investigated for the management of osteoarthritis, the available evidence remains heterogeneous. Several randomized clinical trials and long-term studies have reported improvements in pain relief, joint function, and cartilage preservation, particularly with crystalline glucosamine sulfate formulations. However, systematic reviews and meta-analyses have produced inconsistent conclusions, with some reporting only modest or clinically insignificant benefits compared with placebo (Fernández-Martin et al., 2021). Differences in glucosamine formulations, treatment duration, dosage, patient populations, and study design may account for these discrepancies. Consequently, while glucosamine continues to be widely used as a dietary supplement, further high-quality, standardized clinical trials are required to establish its efficacy across different patient groups (Baden et al., 2025).

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Table 2. Usage effects and areas of glucosamine obtained from different sources

Source	Product	Usage Areas and Effects	References
-	N-acetylglucosamine, Glucosamine sulphate	Accelerating wound healing and increasing the synthesis of healing-supporting substances in the body	McCarty (1996)
Commercial	Glucosamine hydrochloride	Significant antioxidant effect on hydroxy radicals and superoxide radicals	Xing et al. (2006)
Commercial	Glucosamine sulphate	Osteoarthritis treatment, structural joint disease treatment	Chiusaroli et al. (2011), Goldberg et al. (2002), Rubin et al. (2001)
Shellfish	Glucosamine sulphate	Osteoarthritis treatment	Kirkham & Samarasinghe (2009), Pavelká et al. (2002)
Commercial	D- Glucosamine nanoparticles with copper ions	Demonstrated inhibitory activity against *Salmonella typhimurium*, *Enterococcus faecalis*, and *Bacillus subtilis*, affirming its capacity as an anti-infective agent for the safeguarding of medical devices, water treatment, and food processing.	Veerapandian et al. (2012)
Mushroom (*Schizophyllum commune* and *Pleurotus ostreatus*)	N-acetylglucosamine	Pharmaceutical industry	Kalutharage & Rathnasinghe (2020)
Commercial	Glucosamine hydrochloride	Antimicrobial effect on bacteria that cause spoilage in foods (*Bacillus subtilis, Micrococcus luteus, Staphylococcus saprophyticus and Pseudomonas fluorescens*)	Malik et al. (2013)
Commercial	Glucosamine sulphate	Antimicrobial effect on microorganisms of environmental origin by adding it to different nutrients	Rozin (2009)
Commercial	Glucosamine/silk fibril–chitosan	In tissue engineering studies, tissue skeleton formation using glucosamine-silk fibril-chitosan is used to create a porous structure.	Vishwanath et al. (2017)
Commercial	D- Glucosamine hydrochloride	It is used in the water treatment, textile, and pharmaceutical sectors due to its antimicrobial effect against *E. coli* and other similar disease-causing bacteria.	Govindaraju et al. (2015)
Commercial	D(+)-Glucosamine, D(+)-Glucosamine 6-sulphate	Prevention of scar tissue formation following deformation in the skin	Shaunak et al. (2004)
Indian shrimp (*Penaeus monodon*), blue crab (*Portunus pelagicus*), spot crab (*Portunus sanguinolentus*), chitin	Glucosamine hydrochloride	Food and medical applications	Sibi et al. (2013)
Commercial	Glucosamine hydrochloride	The Maillard reaction slows down in foods due to its antimicrobial and antioxidant activity.	Wu et al. (2014)
Commercial	D- Glucosamine	Antimicrobial activity on *Escherichia coli, Staphylococcus aureus and Staphylococcus epidermis* and wider field of biomedical application	Blagodatskikh et al. (2013)
Asperillus niger mycelium	N-Acetyl-D- Glucosamine	Preservative additive in foods due to its antimicrobial properties	Zhu et al. (2016)
Commercial	D-Glucosamine and derivatives	Antimicrobial impact on Gram-positive, Gram-negative and moulds	Matsumura et al. (1993)
Commercial	D-Glucosamine hydrochloride	High inhibition effect of silver ions on 8 Gram-positive and 8 Gram-negative bacteria	Veerapandian et al. (2010)
-	Glucosamine	Elimination of drug resistance caused by the increase of abnormal levels of transglutaminase-2 in some malignant cancer cells and breast cancer cells, and the death of cancer cells with drug resistance	Kim et al. (2009)
Polyethylene glycol, PEG, Succinic anhydride	Glucosamine	Antifungal activity on *Candida albicans*	Mohammadi et al. (2017)

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Glucosamine is a relatively recent inclusion in the nutricosmetic field. It has been observed to suppress melanin formation in the skin, potentially. Glucosamine's ability to block glycosylation, the process of adding polysaccharide units to proteins, has been demonstrated in in vitro melanocyte cell cultures. In addition to its well-established anti-arthritic and anti-ageing effects, recent evidence indicates that glucosamine could reduce the cancer risk. Based on other investigations, glucosamine is beneficial for improving inflammatory bowel disease, migraines, and viral infections. Moreover, several researches suggested anti-inflammatory, antioxidant, antifibrotic, neuroprotective and cardioprotective functions of this amino sugar, making it an ideal nutraceutical supplement to meet various dietary needs. Animal studies have demonstrated that glucosamine has good healing characteristics in peptic ulcers. The oral application of glucosamine facilitates the synthesis of stomachal mucosa, aiding in ulcer repair and providing analgesic effects. Recent studies have asserted that glucosamine supplementation in rats replicated the effects of a low-calorie diet, resulting in an extended lifespan compared to control subjects (Binsi & Zynudheen, 2019).

The antioxidant function of glucosamine hydrochloride was clear, demonstrating significant reducing power and the capacity to scavenge superoxide and hydroxyl radicals. The in vitro findings indicate that glucosamine hydrochloride may be a beneficial component of health or functional diets to mitigate oxidative stress (Xing et al., 2006).

Usage areas and effects of glucosamine and its derivatives obtained from different sources are summarised in Table 2.

A critical comparison of the available evidence indicates that the scientific support for glucosamine applications varies considerably across different fields. Osteoarthritis remains the most extensively studied indication, with numerous randomized clinical trials and systematic reviews reporting improvements in pain management and joint function in selected patient populations (Ogata et al., 2018; Fernandez-Martin et al., 2021; Baden et al., 2025). Nevertheless, inconsistencies among study outcomes suggest that therapeutic efficacy may depend on factors such as glucosamine formulation, dosage, treatment duration, and patient characteristics (Yang et al., 2023; Protity & Zhou, 2025). Beyond osteoarthritis, antioxidant, anti-inflammatory, and antimicrobial activities have been consistently demonstrated in experimental studies, supporting the potential of glucosamine and its derivatives as multifunctional bioactive compounds (Zhang et al., 2026). In contrast, applications in tissue engineering, regenerative medicine, cancer prevention, neuroprotection, and cardiovascular health remain largely supported by in vitro and animal studies, with limited clinical validation. Furthermore, recent advances in biomaterial engineering and microbial biotechnology have expanded the potential applications of glucosamine while emphasizing the need for sustainable production methods and standardized formulations (Liu et al., 2013). Collectively, these findings suggest that although glucosamine exhibits considerable promise across multiple biomedical fields, additional mechanistic investigations and large-scale, well-controlled clinical studies are necessary to establish its long-term efficacy, safety, and translational potential (Prasetyo et al., 2019).

Overall, the reviewed studies demonstrate that glucosamine possesses a broad spectrum of biological activities, including anti-inflammatory, antioxidant, antimicrobial, and tissue-regenerative properties. Nevertheless, the quality of evidence differs substantially among application areas. Therapeutic use in osteoarthritis has been supported by numerous clinical investigations, whereas many proposed benefits in cancer prevention, neuroprotection, cardiovascular health, wound healing, and antimicrobial therapy are derived primarily from in vitro experiments or animal models (Protity & Zhou, 2025; Baden et al., 2025). Therefore, direct translation of these findings into clinical practice should be approached with caution until validated by well-designed human studies. Future research should prioritize standardized formulations, mechanistic investigations, and large-scale clinical trials to better define the therapeutic potential of glucosamine and its derivatives (Zhang et al., 2026).

Conclusion

Contemporary environmental changes and lifestyle-related factors have contributed to the increasing prevalence of joint disorders and other chronic health conditions, leading to growing interest in dietary supplements and nutraceuticals. Among these, glucosamine has received considerable scientific and commercial attention due to its role in cartilage metabolism, tissue repair, and modulation of inflammatory processes. Although glucosamine is widely used in the management of osteoarthritis and related conditions, current evidence regarding its therapeutic efficacy remains heterogeneous, highlighting the need for continued investigation through well-designed clinical studies.

The sustained global demand for glucosamine, reflected by its multibillion-dollar market value, emphasizes the importance

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of not only understanding its biological and clinical applications but also improving the sustainability and efficiency of its production. This review demonstrates that chitin-rich resources, particularly shellfish-derived by-products, remain the primary industrial source of glucosamine. However, increasing attention is being directed toward alternative raw materials and environmentally friendly production approaches to meet future market demands while reducing environmental impacts.

Furthermore, this review highlights the importance of optimizing extraction and processing technologies for glucosamine production. While conventional acid hydrolysis remains the dominant industrial method, emerging enzymatic and biotechnological approaches offer promising alternatives with improved selectivity, reduced environmental burden, and greater potential for sustainable manufacturing. The diversification of glucosamine sources and production strategies will be essential for ensuring long-term supply, product quality, and economic viability.

Future research should focus on the development of green extraction technologies, microbial and enzymatic production systems, and comprehensive life-cycle assessments of glucosamine manufacturing processes. In addition, further investigations into the molecular properties of glucosamine and its derivatives, as well as their synergistic interactions with other bioactive compounds, may facilitate the development of high-purity formulations for targeted medical, pharmaceutical, and nutraceutical applications. Such advances will contribute to a more sustainable and scientifically informed utilization of glucosamine in both industrial and healthcare sectors.

Compliance With Ethical Standards

Authors' Contributions

AEK: Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Writing – review & editing

AK: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Supervision

MC: Conceptualization, Methodology, Writing – review & editing, Supervision

CP: Conceptualization, Methodology, Writing – review & editing

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Funding

Not applicable.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

AI Disclosure

The authors confirm that no generative AI was used in creating images, tables, or graphics. AI-assisted technology was not used in the preparation of this work, except for grammar and spelling checks. The authors validated all outputs and assume full responsibility for the content.

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