This comprehensive review explores Vitamin C (Ascorbic Acid), examining its properties, sources, and significant health benefits

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Abstract: Vitamin C, also known as ascorbic acid, is a water-soluble vitamin that plays a vital role in numerous physiological processes. It is essential for collagen synthesis, immune function, wound healing, and the protection of cells from oxidative damage. This review delves into the chemical and physical properties of Vitamin C, including its molecular structure, solubility, stability, and sensitivity to environmental factors such as heat, light, and oxygen. The document discusses both natural and synthetic sources of Vitamin C, highlighting plant-based sources such as citrus fruits, berries, and leafy greens, along with synthetic forms used in dietary supplements and fortified foods.The pharmacological activities of Vitamin C are extensively covered, particularly its antioxidant properties, which help neutralize free radicals and reduce the risk of chronic diseases like cardiovascular diseases, cancer, and neurodegenerative disorders. The paper also explores its immune-boosting effects by stimulating white blood cell production and supporting the function of immune cells. Additionally, Vitamin C is critical for collagen formation, ensuring the integrity of skin, bones, and connective tissues, and its deficiency can lead to conditions such as scurvy, which manifests with symptoms like bleeding gums and joint pain.

The role of Vitamin C in enhancing iron absorption, its potential anticancer properties, neuroprotective effects, and contribution to cardiovascular health are also discussed. Furthermore, the document addresses the therapeutic use of Vitamin C in managing diabetes, improving blood sugar regulation, and promoting skin health by reducing wrinkles and protecting against UV-induced damage.While the benefits of Vitamin C are extensive, the paper also examines the adverse effects of excessive intake, such as gastrointestinal disturbances, kidney stones, and interactions with certain medications. The discussion concludes with an overview of popular Vitamin C formulations in the market, including supplements and topical applications like serums for skin care, underlining the importance of proper Vitamin C consumption for maintaining optimal health.

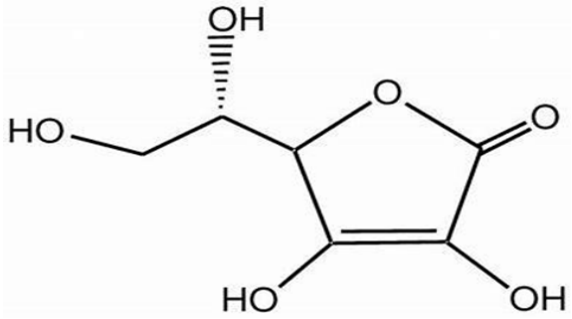
INTRODUCTION

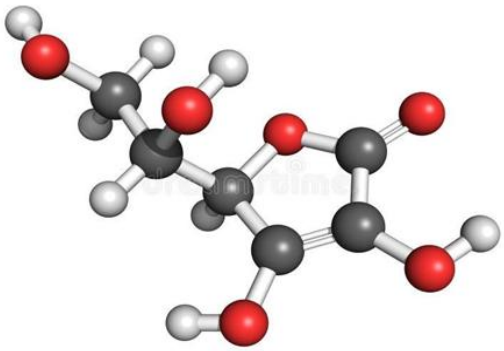
Vitamin C, scientifically known as Ascorbic Acid, is a vital water-soluble vitamin with numerous biological roles that are essential for human health. As a powerful antioxidant, it helps protect the body against oxidative stress by neutralizing free radicals and reactive oxygen species (ROS). Vitamin C is also involved in the synthesis of collagen, a key protein for skin, cartilage, and bones, thereby contributing to wound healing and skin elasticity. Beyond its antioxidant capabilities, Vitamin C plays a significant role in enhancing immune function by promoting the production and activity of white blood cells, including neutrophils and T-cells, which are crucial for defending against infections. Humans, unlike many animals, cannot synthesize Vitamin C and must obtain it from dietary sources. These sources include a variety of fruits and vegetables, with citrus fruits such as oranges and lemons being particularly well known for their high Vitamin C content. Other sources include berries, bell peppers, kiwi, and leafy greens. In addition to natural sources, synthetic forms of Vitamin C, such as ascorbic acid supplements, are widely available and commonly used to prevent deficiency. The chemical structure of Vitamin C includes a six-carbon chain with hydroxyl groups and a lactone ring, which makes it highly sensitive to environmental factors. Its stability is influenced by temperature, light exposure, pH, and oxygen, making it prone to degradation under certain conditions. This sensitivity is why proper storage and handling of Vitamin C-rich foods and supplements are necessary to preserve their nutritional value.

Beyond its well-known antioxidant and immune-boosting effects, Vitamin C has been linked to the prevention of chronic diseases, including cardiovascular disease, certain cancers, and neurodegenerative disorders. It also plays a role in iron absorption, reducing the risk of iron deficiency anemia, and supports overall skin health, making it a common ingredient in skincare products. Despite its availability in many foods, Vitamin C deficiency remains a concern, particularly among individuals with limited access to fresh fruits and vegetables. The most common disease associated with deficiency is scurvy, characterized by fatigue, joint pain, bleeding gums, and impaired wound healing. Other signs of deficiency include weakened immunity, dry skin, and iron deficiency anemia. This document delves into the many aspects of Vitamin C, from its chemical properties and stability to its critical pharmacological activities. It highlights the wide-ranging benefits of maintaining adequate Vitamin C intake and underscores the potential health risks associated with deficiency.

Chemical Name: Ascorbic acid
Molecular Formula: $C_6H_8O_6$
IUPAC Name: (5R)-5-[(1S)-1,2-dihydroxyethyl]-3,4dihydroxyfuran-2(5H)-one

Chemical & 3D structure of vitamin C:





Category	Synonyms
Chemical Names	Ascorbic Acid, L-Ascorbic Acid
Pharmaceutical Terms	C-Vit, Antiscorbutic Factor, Ce-Vit
Dietary/General Terms	Vitamin C Complex, Water-Soluble Vitamin C

Sources of Vitamin C:
Plant-Based Sources: [1,2]

The majority of vitamin C is derived from fruits and vegetables.

1) Citrus Fruits: Oranges, lemons, grapefruits, and limes are famous for their high vitamin C content.
2) Berries: Strawberries, raspberries, blackberries, and blueberries.
3) Kiwi: An excellent source of vitamin C.
4) Papaya: Rich in vitamin C, along with other antioxidants.
5) Bell Peppers: Both green and red peppers are high in vitamin C.
6) Leafy Greens: Spinach, kale, and Swiss chard.
7) Tomatoes: Both fresh and cooked tomatoes contribute vitamin C.
8) Other Vegetables: Broccoli, Brussels sprouts, and cauliflower.

2. Synthetic Sources of Vitamin C [3,4]

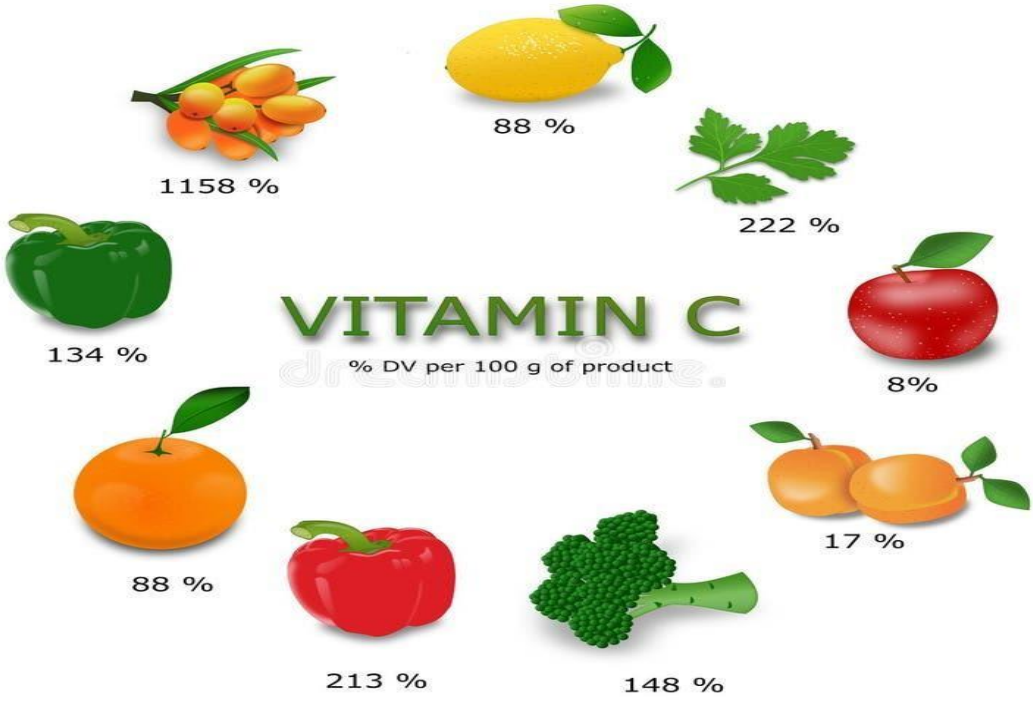
1) Ascorbic Acid: This is the most common form of vitamin C found in supplements and fortified foods. It is chemically identical to the vitamin C found in natural sources.
2) Sodium Ascorbate and Calcium Ascorbate: These are mineral salts of ascorbic acid, commonly used in supplements and are considered less acidic than ascorbic acid.
   - Synthetic vitamin C is made from glucose derived from corn, fermented by bacteria to

form ascorbic acid, it is chemically identical to natural vitamin C and is often used in supplements or as a food additive [4]

3. Animal-Derived Sources of Vitamin C [5,6]

1) Liver: Some animals, such as cows, have high vitamin C levels in their liver, although human consumption of this source is uncommon.
2) Fish: Certain fishlike salmon may contain vitamin C in small amounts, especially when consumed raw or minimally processed.
3) Organs and Tissues: Other organs, including the kidney and adrenal glands, in some animals, have notable vitamin C content, though these are not typically consumed by humans.

- Humans, unlike most animals, do not produce vitamin C and must obtain it from dietary sources, some animals can synthesize their own vitamin C from glucose in the liver, but humans lack the necessary enzyme (L-gulonolactone oxidase) for this processed [6]



Physical and Chemical Properties of Vitamin C (Ascorbic Acid) 1. Physical Properties [8,9]

Property	Details
Molecular Formula	C6H8O6
Molecular Weight	176.12 g/mol
Structure	Contains a six-carbon chain with hydroxyl (-OH) groups and a lactone ring.
Physical State	White to slightly yellow crystalline powder
Melting Point	190-192°C (with decomposition)
Solubility	Highly soluble in water (330 g/L at 20°C); slightly soluble in ethanol; insoluble in nonpolar solvents like ether.
Taste	Characteristic sour taste
pH (in solution)	Acidic typically around 2-3 for a 5% aqueous solution
Stability	Stable in dry form but highly sensitive to environmental factors like heat, light, oxygen, and pH.

2. Chemical Properties [11,12]

Property	Details
Acidic Nature	Contains enolic hydroxyl groups, making it a weak acid. Reacts with bases to form salts such as sodium ascorbate.
Redox Activity	Functions as a reducing agent; gets oxidized to dehydroascorbic acid. Can reduce metal ions and free radicals.
Oxidation Sensitivity	Oxidizes easily in the presence of air, light, or metal ions, leading to degradation products like diketogulonic acid.
pH Dependency	Stable under acidic conditions; degrades rapidly in neutral or alkaline environments.
Reaction with Iodine	Reduces iodine to iodide, commonly used in titration methods to measure vitamin C content.
Chelation Ability	Forms complexes with metal ions (e.g., iron), enhancing their solubility and bioavailability.

Stability and Degradation of Vitamin C (Ascorbic Acid)

Vitamin C, while essential and beneficial, is a highly unstable molecule that can degrade under various environmental and storage conditions.

Factors Affecting Stability:

1. Temperature:

a) High temperatures accelerate the degradation of vitamin C. Prolonged heating during cooking can result in significant losses, often up to 50-60% depending on the food and cooking method

b) Vitamin C is relatively stable at low temperatures, which is why refrigeration is recommended for preserving its content in fresh produce. [7,8]

2. Light Exposure:

a) Vitamin C is sensitive to light, particularly UV light. This exposure can cause oxidation, leading to a rapid decline in its concentration.[9]

3. pH:

a) Vitamin C is most stable in acidic conditions (pH < 4). In neutral or alkaline environments, it degrades more rapidly into inactive compounds.[10]

4. Oxygen:

a) Exposure to oxygen leads to the oxidation of ascorbic acid to dehydroascorbic acid, which is less stable and eventually degrades into diketogulonic acid, rendering it biologically inactive.

b) Packaging and storage in airtight containers or vacuum-sealed conditions can minimize this degradation.[11]

5. Metal Ions:

a) Metals like iron and copper can catalyze the oxidative degradation of vitamin C. This is why avoiding metallic containers for storage is recommended.[11]

Degradation Pathways [12,13]

Degradation Type	Pathway	End Products
Oxidative Degradation	- Ascorbic Acid → Dehydroascorbic Acid (DHA) (reversible) - DHA → 2,3-Diketogulonic Acid (irreversible)	Diketogulonic acid, furans, and oxalates
Thermal Degradation	- Heat cleaves the lactone ring of ascorbic acid.	Inactive compounds such as furfural derivatives
Photo-Degradation	- UV light breaks the lactone ring.	2-Furoic acid and other breakdown products

Pharmacological activities of Vitamin C (Ascorbic Acid):

1. Antioxidant Activity

Ascorbic acid is a potent antioxidant, protecting cells and tissues from oxidative stress by neutralizing free radicals and reactive oxygen species (ROS). It acts through direct electron donation, which helps in the regeneration of other antioxidants, such as vitamin E, and prevents cellular damage caused by oxidative

stress. The antioxidant property of Vitamin C is critical in preventing chronic diseases such as cardiovascular diseases, cancer, and neurodegenerative disorders.[15]

2. Immune System Enhancement

Vitamin C is known to enhance the immune system by stimulating the production of white blood cells (particularly neutrophils) and supporting their function. It increases the production of interleukin-1 and interferon, molecules involved in the immune response. Moreover, it promotes the function of T-cells and natural killer cells, which are essential for the body's defense against infections.[16]

3. Collagen Synthesis

Vitamin C is a crucial cofactor for proline hydroxylase and lysyl hydroxylase, enzymes that are involved in the synthesis of collagen. Collagen is a structural protein essential for skin, bones, and connective tissues. Deficiency in Vitamin C leads to weakened collagen formation, causing conditions like scurvy, which results in bleeding gums, joint pain, and impaired wound healing.[17]

4. Anticancer Potential

Recent studies have suggested that Vitamin C possesses anticancer properties. It inhibits cell proliferation, induces apoptosis (programmed cell death), and modulates signaling pathways involved in tumorigenesis. High doses of Vitamin C have been shown to reduce the growth of cancer cells in vitro, particularly in glioblastoma, leukemia, and ovarian cancer cells. It also enhances the effect of conventional chemotherapy drugs when used as an adjunct therapy.[18]

5. Cardiovascular Health

Vitamin C plays a significant role in maintaining cardiovascular health. It improves endothelial function, enhances vascular relaxation, and reduces the risk of hypertension. By reducing oxidative stress, it helps in the prevention of atherosclerosis (hardening of arteries), and high levels of Vitamin C are associated with lower blood pressure and a reduced risk of heart disease.

It also improves lipid metabolism and reduces cholesterol levels in the blood.[19]

6. Neuroprotective Activity

Ascorbic acid is involved in the synthesis of neurotransmitters such as dopamine and norepinephrine, which are crucial for brain function and mood regulation. It also has neuroprotective properties due to its antioxidant activity, which helps prevent neurodegenerative diseases like Parkinson's disease and Alzheimer's disease. Additionally,

Vitamin C supports the blood-brain barrier, promoting brain health and cognitive function.[20]

7. Anti-inflammatory Effects

Vitamin C has been shown to reduce inflammatory markers and lower the activity of proinflammatory cytokines such as TNF-alpha and interleukin-6 (IL-6). This makes it beneficial in conditions like rheumatoid arthritis, osteoarthritis, and other inflammatory diseases. Its ability to neutralize oxidative stress also contributes to its anti-inflammatory effects.[21]

8. Role in Iron Absorption

Vitamin C enhances the absorption of non-heme iron (the iron found in plant-based foods) by reducing iron to its ferrous (Fe^{2+}) state, which is more easily absorbed in the intestines. This is particularly beneficial for individuals at risk of iron deficiency, such as vegetarians and pregnant women.[16]

9. Skin Health

Vitamin C plays a pivotal role in skin health by supporting the synthesis of collagen, which helps maintain skin elasticity and repair. It also has wound-healing properties and is commonly used in skincare products to brighten the skin, reduce wrinkles, and protect against UV-induced skin damage. Vitamin C can protect the skin from photoaging and skin cancer by neutralizing free radicals generated by UV radiation.[22]

10. Diabetes and Blood Sugar Regulation

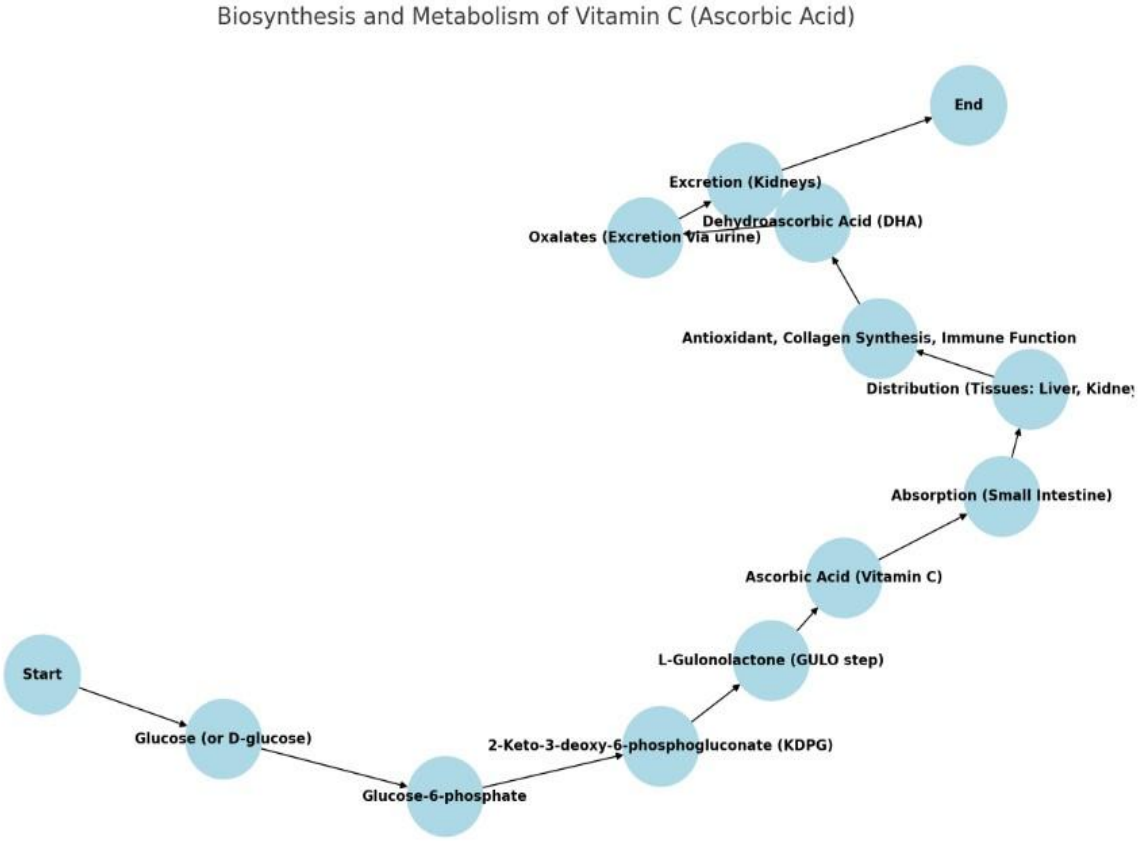
Vitamin C has shown potential in helping to regulate blood sugar and improving insulin sensitivity. Research indicates that it may reduce hyperglycemia in individuals with type 2 diabetes and prevent long-term complications like diabetic retinopathy. Vitamin C’s antioxidant effect may also reduce oxidative stress

associated with diabetes, further supporting its therapeutic use in managing the disease. [17,18]

11. Wound Healing

Vitamin C accelerates wound healing by promoting collagen synthesis, which is vital for tissue repair. It is used in the treatment of burns, surgical wounds, and chronic ulcers. Vitamin C's antioxidant properties also help reduce oxidative stress at the wound site, thus improving the healing process and reducing the risk of infection.[17]

Biosynthesis and Metabolism: [12]



Vitamin C Deficiency [15,16,17]

Vitamin C deficiency can lead to a range of health issues, primarily due to its role in collagen synthesis, antioxidant activity, and immune function. The severity of deficiency varies depending on the duration and extent of the lack of Vitamin C in the diet.

1. Scurvy

The most well-known disease associated with Vitamin C deficiency is scurvy, characterized by:

- Fatigue
- Gum bleeding
- Loose teeth
- Joint pain and swelling
- Bruising and easy bleeding

Scurvy occurs after several months of inadequate Vitamin C intake. Collagen production is impaired, affecting the skin, blood vessels, bones, and cartilage.

2. Weak Immune System

Vitamin C is essential for proper immune function. Its deficiency can lead to increased susceptibility to infections, delayed wound healing, and prolonged illnesses.

- Frequent infections
- Slow recovery from wounds

3. Poor Collagen Synthesis

Vitamin C plays a crucial role in collagen formation, which is important for the health of skin, cartilage, tendons, ligaments, and blood vessels. A lack of Vitamin C can impair wound healing and affect skin and joint health.

- Slow wound healing

- Skin issues like rough, dry patches

4. Iron Deficiency Anemia

Vitamin C enhances non-heme iron absorption from plant-based foods. A deficiency may worsen iron deficiency anemia, leading to symptoms like fatigue, weakness, and pale skin.

5. Dry and Split Hair

Due to its role in collagen production and antioxidant activity, Vitamin C deficiency can lead to dry, brittle hair, and split ends.

6. Psychological Symptoms

Severe Vitamin C deficiency has been associated with symptoms like irritability, depression, and cognitive dysfunction due to its role in neurotransmitter synthesis.

7. Swollen and Bleeding Gums

Gingivitis (swollen, inflamed gums) and bleeding gums are early signs of Vitamin C deficiency. As deficiency progresses, tooth loss and other oral issues can occur.

At-risk Groups for Vitamin C Deficiency

- Smokers (who have a higher turnover of Vitamin C)
- Elderly individuals with limited food intake
- People with poor dietary habits (low fruit and vegetable intake)
- Infants who are not breastfed or lack Vitamin C-fortified formula

Adverse Drug Reactions (ADRs) of Vitamin C

1. Gastrointestinal Disturbances: High doses can cause diarrhea, nausea, vomiting, and abdominal cramping.
2. Kidney Stones: Excessive Vitamin C may increase the risk of calcium oxalate kidney stones, especially in susceptible individuals.
3. Iron Overload: In individuals with hemochromatosis, high doses may exacerbate iron overload, leading to organ damage.
4. Hemolysis: High doses may cause hemolysis in individuals with G6PD deficiency.
5. Hypoglycemia: Diabetic patients may experience low blood sugar when combining Vitamin C with insulin or oral hypoglycemics.
6. Allergic Reactions: Rare reactions include rash, swelling, and difficulty breathing.
7. Medication Interactions: Vitamin C may interfere with chemotherapy, anticoagulants, and oral contraceptives, altering their effectiveness.
8. Overdose: Chronic high doses (above 2,000 mg/day) can lead to toxicity, causing kidney damage and stone formation.

Vitamin C formulations available in the market, along with their brand names:

1. Nature Made Vitamin C (500 mg) – Available in softgel form, offering a moderate daily dose suitable for most individuals.
2. Swanson C-500 – Also providing 500 mg per capsule, known for being affordable and independently verified for quality.
3. Emergen-C Crystals – A unique powdered form with 1,000 mg of Vitamin C per serving, popular for immune support, especially when traveling.
4. LivOn Laboratories Lypo-Spheric Liposomal Vitamin C – Known for its high bioavailability and absorption, this formulation delivers 1,000 mg of Vitamin C.
5. TruSkin Vitamin C Facial Serum – A popular skincare serum containing 20% Vitamin C, suitable for brightening and hydrating all skin types.
6. Drunk Elephant C-Firma Fresh Vitamin C Day Serum – A high-potency serum with a 15% concentration, offering brightening and anti-aging benefits.
7. Biossance Squalane + Vitamin C Rose Oil – A luxurious, oil-based serum with Vitamin C that hydrates and plumps the skin, perfect for dry skin.

CONCLUSION

Vitamin C formulations have revolutionized the accessibility and application of this essential nutrient, offering tailored solutions to meet diverse health and wellness needs. The development of synthetic Vitamin C forms such as ascorbic acid, sodium ascorbate, and calcium ascorbate has enhanced bioavailability and stability, addressing the limitations of natural sources. These formulations are pivotal in dietary supplements, fortified foods, and topical applications. Innovative delivery systems, such as liposomal Vitamin C and highpotency serums, ensure effective absorption and targeted benefits, particularly in skin health and immune support. The growing range of formulations,

from powders and capsules to serums and oils, provides consumers with flexibility in integrating Vitamin C into their routines.

In conclusion, advancements in Vitamin C formulations underscore its versatility and potential in therapeutic and preventative care. As research progresses, optimizing these formulations for enhanced stability, efficacy, and safety will continue to expand their role in promoting overall health and combating disease.

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