- PHILIPPINE JOURNAL OF -

CHEMISTRY

ISSN: 2984-8075

JOURNAL OF CHEMISTRY

VOLUME-9, ISSUE-01, (2026)

EDITOR-IN-CHIEF

ASSOCIATE EDITORIAL BOARD

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JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |16-01-2026|

UDK 547.66.091

RESEARCH OF THE PHYSICOCHEMICAL PROPERTIES OF A COPOLYMER SYNTHESIZED ON THE BASIS OF AN ACRYLIC MONOMER AND A URETHANE OLIGOMER

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ANNOTATION

In the practical experiments of this study, research in the field of synthesis of the acrylic (acrylate)-urethane copolymer based on local raw materials and the creation of technology to further enhance the adhesive strength properties of this copolymer are important. In this field of research, the main attention was paid to the basic physico-chemical properties of the synthesized copolymer, the economic efficiency of its production and the production of starting materials from local raw materials. During the study, a copolymer was obtained in the presence of an acrylic (acrylate) monomer and a urethane oligomer, and its physico-chemical properties were studied.

Keywords: acrylic (acrylate) monomer, urethane oligomer, free radical copolymerization, copolymer, spectroscopy.

INTRODUCTION

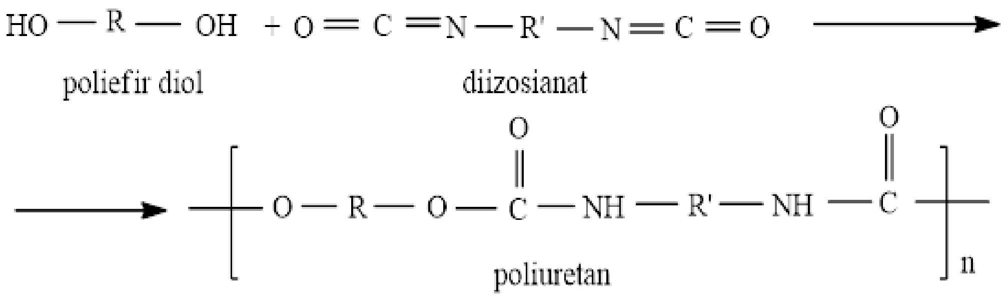
Currently, in the synthesis of adhesion-resistant copolymers with acrylic (acrylate) varnish, nitrogenous urethane oligomers are one of the most common compounds in the modern high-molecular industry. The global production of such nitrogenous urethanes ranges from 8 to 9 million tons per year, which accounts for 6% of the polymer industry [1]. This in turn is the reason why research work in the field of high molecular substances with nitrogen-retaining urethane oligomers in the formation of adhesion copolymers with an acrylic (acrylate) monomer is being carried out intensively [2-3].

In continuation of these studies, the acrylic-urethane copolymer was obtained in practical experiments based on an acrylic monomer and a urethane oligomer and its physico-chemical properties were investigated.

LITERATURE REVIYEW

One of the most promising areas of acrylic monomer-based copolymers in the world are copolymers involving an acrylic monomer and a polyurethane oligomer. Today, the production of polyurethane on an industrial scale is the most widespread branch of the modern polymer industry [4]. According to data analysis, flexible polyurethanes account for about 66% of synthetic materials production in global production, hard foamed plastics account for 22%, and other polymer products account for 12% [5].

Although the synthesis of polyurethanes was first obtained in the laboratory in the nineteenth century, by 1930 the production of fibers, adhesive polymers and coatings from polyurethane oligomer was scientifically confirmed [6]. Several methods are used to produce polyurethanes on an industrial scale. Today, polyurethanes are widely used in many industries due to their diversity. Such properties of polyurethanes as mechanical hardness, high chemical resistance and resistance to climatic influences have led to their widespread use in the form of various copolymers [7].



Polyurethane oligomer, with a global production of 8-9 million tons per year, is widely used in the construction and automotive industries (fig.1) in accordance with the above properties [7].

Upon preparation of the polyurethane-acrylate copolymer, an acrylic monomer and a polyurethane oligomer are obtained and obtained by free radical copolymerization in solution. The polymer product obtained during the experiment is precipitated in methanol and dried in vacuum at a temperature of $40^{O}C$ [8]. It was also proposed to obtain a polyurethane-acrylate copolymer obtained in the presence of a polyurethane oligomer and an acrylic monomer, a thermo- and moisture-resistant coating with acrylic polyurethane paint in the presence of binding agents and organic solvents.

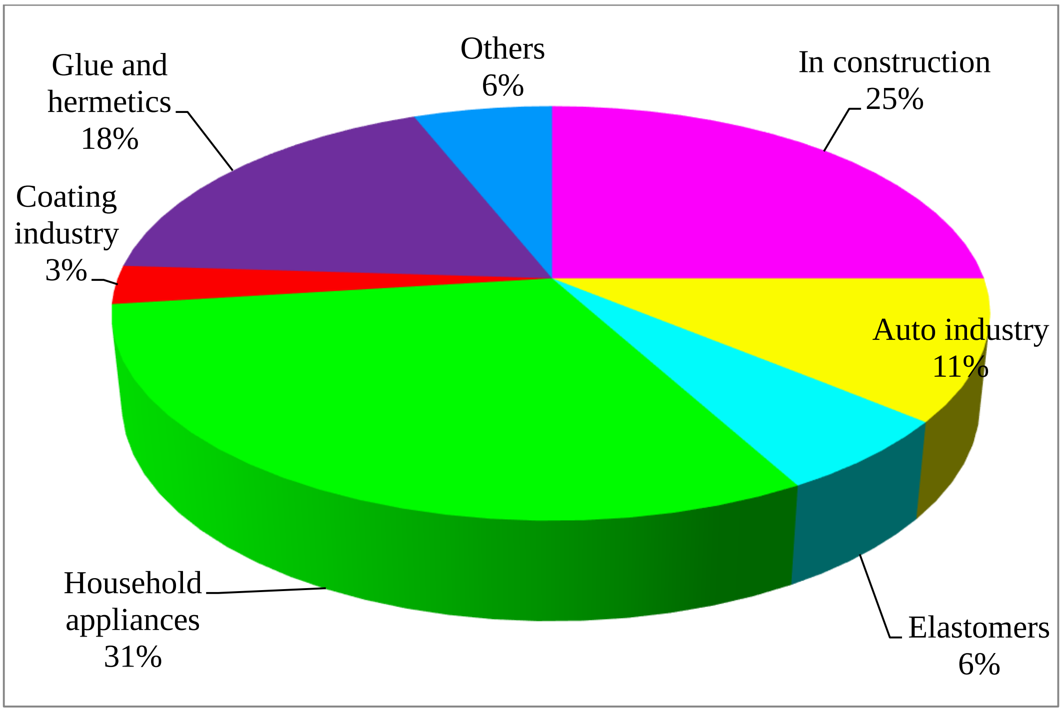


Figure 1. Areas of application of the urethane oligomer.

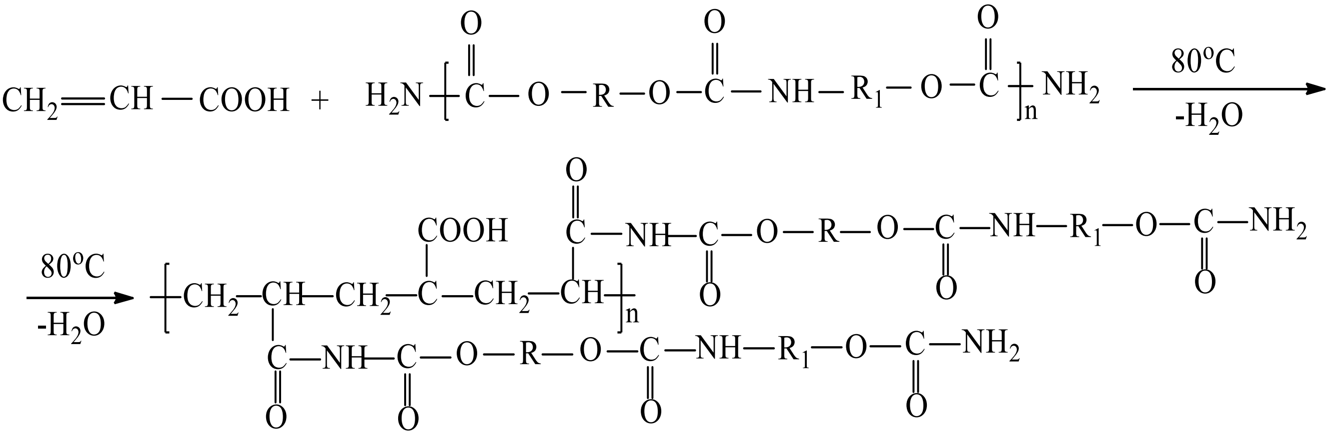
As a continuation of such research work, the specific characteristics of the copolymerization reaction and the resulting copolymer were considered, which go on the basis of an acrylic monomer based on local raw materials and a nitrogen-retaining urethane oligomer in the composition. In particular, during the carried out study, an acrylic-urethane copolymer was synthesized with the acryl monomer based on a free radical copolymerization reaction in the presence of a nitrogen-retaining urethane oligomer in its composition.

RESEARCH METHODOLOGY

In the practical experiments of this study, an acrylic-urethane copolymer was obtain because of the reaction of the copolymerization of the acrylic monomer and the urethane oligomer. The physical and chemical properties of the resulting copolymer were study according to the existing methodology.

METHODS AND MATERIALS.

In practical experiments, work was carry out to obtain an acrylic-urethane copolymer. In this case, a three-headed flask, a cooler and a dropper were obtain, equipped with a thermometer, a heating device and a mechanical stirrer. The urethane oligomer and acrylic monomers were obtain as the initial organic monomers. In practical experiments, a urethane oligomer with a content of nitrogen preservative, an average molecular weight of 700-800, was taken from the compound as well as acrylic acid in a ratio of 1:1 and a copolymerization reaction was carried out at a temperature of 80-90^{O}C for 8 hours, in a nitrogen environment.



$$CH_2{=}CH-COOH + H_2N\left[\overset{O}{\overset{\|}{C}}-O-R-O-\overset{O}{\overset{\|}{C}}-NH-R_1-O-\overset{O}{\overset{\|}{C}}\right]_n NH_2 \xrightarrow[-H_2O]{80^oC}$$

RESULTS AND DISCUSSIONS.

The characteristics of the IR spectra of the copolymer were also study in order to study the chemical bonds and existing functional groups of the copolymer obtained because of the copolymerization reaction occurring between the acrylic monomer and the urethane oligomer (fig. 2).

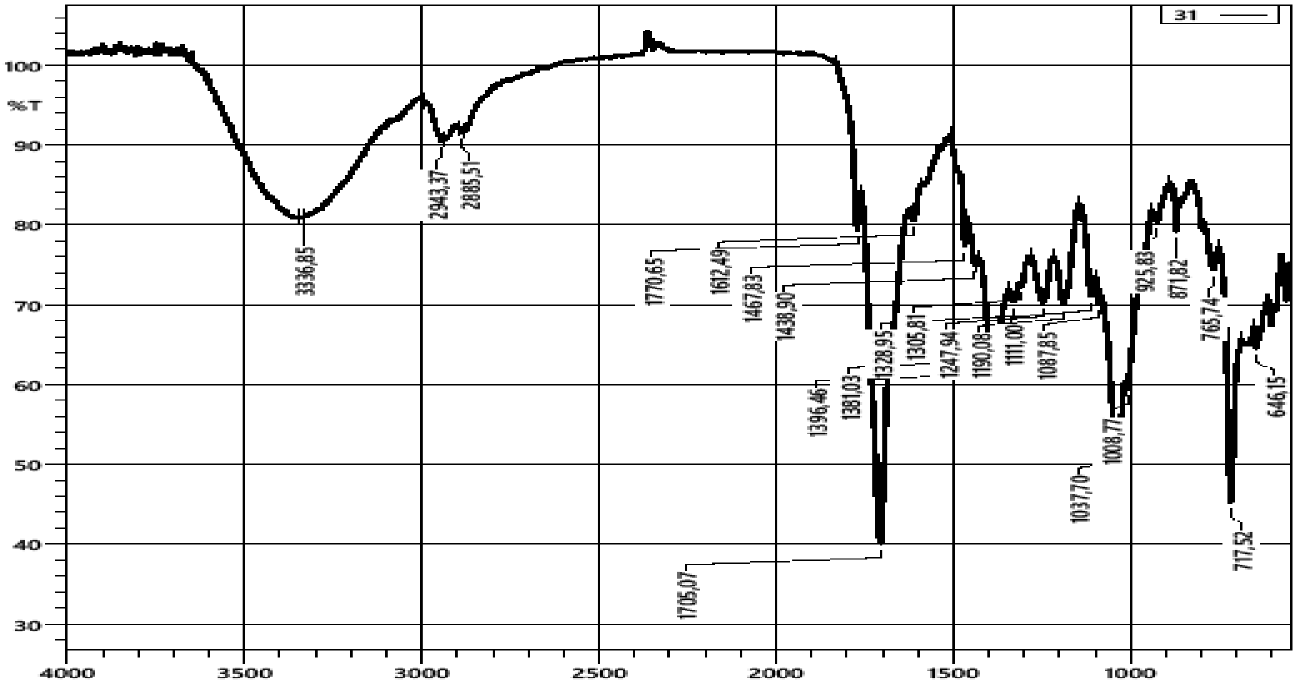


Figure 1. Indicators of the IQ spectrum of acrylic-urethane sopolimer.

To test-experiment the IR-spectroscopy method, a sample of the acrylic-urethane copolymer obtained during the practical experiments was taken in the emulsion aggregate state. The resulting sample was placed in a special pribori (IRAffinity-1s (Shimadzu). With the help of a special pribor, vibrational spectra were obtained through the transfer of infrared light from the sample composition. In this method, at the expense of infrared rays transferred from the sample macromolecule, the fluctuations of the bonds were determined in relation to the dipole moment.

It was found that the spectrum of atoms in the sample obtained in this case consists of thin lines. During the passage of infrared light from the sample, determining frequency indicators of groups were determined under the influence of a factor associated with the passage of light between the oscillations of the macromolecule.

In particular, the indicators obtained for studying the chemical bonds and existing functional groups of acrylic-urethane copolymer were analyze. According to the results obtained, 3336 cm^{-1} belongs to the moderately strong valence vibration – CONHR group in the field. 2913-2885 cm^{-1} strong valence vibration fields-CH_2 - group, 1770 cm^{-1} belongs to the RR'N-COOR urethane group in the field of deformation vibration. 1705 cm^{-1} strong valence vibration field C═O group, 1612 cm^{-1} deformation vibration field - NH_2 group, 1037 - 1008 cm^{-1} strong valence 717-646 cm^{-1} weak valence has been found to have absorbents belonging to the C-S group at the expense of sulfur contained in the initiator added in the vibration areas.

The main distinguishing features of this synthesized copolymer, obtained based on a nitrogen-containing urethane oligomer and an acrylic monomer, were investigate in accordance with the requirements of current regulations (GOST). In particular, when studying the appearance of the synthesized copolymer, it was found that it is a dark oily (density 1.07 g /cm3) chemical composition at a temperature of $20^{O}C$. dark red, and that this substance belongs to hazard class 4 with a low hazard level according to GOST 12.1.007-76.

Also, according to the characteristics of the synthesized nitrogenous copolymer acrylic - urethane, it was found that the pH value is in the range 7.5-9.0 (table 1).

TABLE 1

The main nitrogen retention parameters of the acrylic-urethane copolymer in the synthesized copolymer are determined.

o/n	Index name	Mark	Unit of measurement	Detection method and description
1	Appearance and color	-	-	Visually, dark greasy in dark red
2	Density	$\rho = m/v$	g/sm^3	15139, 1,07
3	Hydrogen indicator	pH	-	Using the indicator, 7,5-9.0
4	Hazard level	-	-	GOST 12.1.007-76, 4-class

In the course of the experiments, the solubility property of an acrylic-urethane copolymer with adhesive properties in synthesized solvents was investigate. According to the research results, a good solubility of the synthesized copolymer in water and other organic solvents at room temperature was reveal (table 2).

TABLE 1

Solubility of acrylic-urethane copolymer

o/n	Solvent name	Melting temperature	Melting index (%)
1	Water	$20^{o}C$	60 %
2	Ether	$20^{o}C$	25 %
3	Alcohol	$20^{o}C$	20 %

Thus, according to the results obtained during the study of the physico-chemical properties of the nitrogen-preserving acrylic-urethane copolymer in the composition, it is consider advisable in the future to create a production technology for its extraction from local raw materials.

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JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |19-03-2026|

TECHNOLOGY OF PRODUCING ANTICORROSIVE COATINGS BASED ON NANO-SIZED PARTICLES

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ABSTRACT

This article examines the scientific and technological basis of anticorrosive coatings formulated with nano-sized particles, the principal classes of nanofillers used in coating systems, their interaction with polymer matrices, and the key stages of coating formation. Corrosion remains one of the main causes of service-life reduction in metal structures, pipelines, transport equipment, agricultural machinery, and chemical apparatus. Conventional coatings often fail under moisture, chloride exposure, ultraviolet radiation, and mechanical damage. The incorporation of nano-sized fillers into epoxy, polyurethane, and sol-gel matrices can improve coating density, barrier behavior, adhesion, resistance to microcracking, and long-term protective performance. The paper discusses the roles of SiO2, ZnO, TiO2, Al2O3, graphene oxide, nanoclays, and related nanofillers. Rather than inventing laboratory data, the study follows an analytical IMRAD structure based on literature synthesis, comparison of composition–property relationships, and stage-by-stage modeling of the technological route. The analysis shows that when nanoparticle loading and dispersion are properly controlled, coating resistance to corrosive media, mechanical integrity, and operational durability improve substantially.

Keywords: nanoparticles, anticorrosive coating, epoxy composite, graphene oxide, ZnO, SiO2, sol-gel, barrier mechanism, dispersion, corrosion protection.

АННОТАЦИЯ

В данной статье рассматриваются научные и технологические основы антикоррозионных покрытий, созданных с использованием наночастиц, основные классы нанонаполнителей, применяемых в системах покрытий, их взаимодействие с полимерными матрицами и ключевые этапы формирования покрытия. Коррозия остается одной из основных причин сокращения срока службы металлических конструкций, трубопроводов, транспортного оборудования, сельскохозяйственной техники и химического оборудования. Традиционные покрытия часто выходят из строя под воздействием влаги, хлоридов, ультрафиолетового излучения и механических повреждений. Включение наноразмерных наполнителей в эпоксидные, полиуретановые и золь-гелевые матрицы может улучшить плотность покрытия, барьерные свойства, адгезию, устойчивость к микротрещинам и долговременную защитную эффективность. В статье обсуждается роль SiO2, ZnO, TiO2, Al2O3, оксида графена, наноглины и связанных с ними нанонаполнителей. Вместо того чтобы изобретать лабораторные данные, исследование следует аналитической структуре IMRAD, основанной на синтезе литературных данных, сравнении соотношений состава и свойств и поэтапном моделировании технологического процесса. Анализ показывает, что при надлежащем контроле загрузки и дисперсии наночастиц существенно улучшаются стойкость покрытия к коррозионным средам, механическая целостность и эксплуатационная долговечность.

Ключевые слова: наночастицы, антикоррозионное покрытие, эпоксидный композит, оксид графена, ZnO, SiO2, золь-гель, барьерный механизм, дисперсия, защита от коррозии.

INTRODUCTION

Corrosion is a persistent materials-engineering problem that causes economic loss, safety hazards, and reduced reliability across a wide range of industries. Once a metallic surface is exposed to oxygen, moisture, salts, acids, alkalis, or industrial atmospheres, electrochemical degradation may begin. In practical terms, a protective coating is not merely a decorative layer; it is a functional barrier that interrupts the transport of aggressive species toward the substrate.

During the last decade, nanostructured and nanoparticle-filled coatings have emerged as one of the most promising strategies in corrosion protection. Their appeal lies in the unique features of nano-sized particles: high specific surface area, strong interfacial activity, the ability to occupy microvoids in polymer matrices, and the capacity to create tortuous diffusion pathways. These features can reduce water uptake, slow oxygen transport, improve adhesion, and increase the service life of the coating system.

However, a weak assumption often appears in low-quality discussions of nanocoatings: the idea that adding nanoparticles automatically improves corrosion resistance. That assumption is wrong. Agglomeration, poor wetting, improper surface treatment, excessive filler loading, and uncontrolled curing can create defects rather than protection. The technology of producing anticorrosive nanocoatings must therefore be understood as a complete process that includes substrate preparation, nanoparticle dispersion, formulation design, application method, and curing schedule.

The objective of this paper is to present, in IMRAD form, a rigorous overview of the technology used to produce anticorrosive coatings based on nano-sized particles, to compare the main nanofiller families, to explain their protection mechanisms, and to outline a realistic technological route suitable for adaptation in research and industrial practice.

MATERIALS AND METHODS

This study does not fabricate experimental measurements. Instead, it uses an analytical research design based on the synthesis of journal articles, review papers, coating technology reports, and practical formulation logic reported in the field of anticorrosive nanocomposite coatings. This approach is appropriate when the goal is to build a scientifically grounded article draft without claiming laboratory results that were never obtained.

The analysis focuses on three major matrix types: epoxy, polyurethane, and sol-gel systems. The nanofillers considered include silica (SiO2), zinc oxide (ZnO), titanium dioxide (TiO2), alumina (Al2O3), graphene oxide, carbon-based nanostructures, and layered nanoclays. Evaluation criteria include barrier performance, adhesion, water absorption, hardness, scratch resistance, diffusion-path tortuosity, coating integrity, and long-term stability under corrosive exposure.

The technological route was decomposed into five stages. First, the metal substrate must be mechanically and chemically cleaned in order to remove rust, oxide scale, grease, and weakly bonded contaminants. Second, nanoparticles must be transformed into a stable dispersion using suitable solvents, dispersants, high-shear mixing, or ultrasonic treatment. Third, the dispersion must be incorporated gradually into the polymer matrix while controlling viscosity and avoiding re-agglomeration. Fourth, the coating is applied by spraying, dip-coating, roll-coating, or brushing depending on the substrate geometry and production constraints. Fifth, curing and post-curing conditions are selected to ensure network formation without internal stresses or microdefects.

From a formulation standpoint, nanoparticle concentration is a critical variable. Too little filler yields negligible benefit. Too much filler raises viscosity, worsens processing, promotes aggregation, and may generate internal stress concentration points. For that reason, the method section emphasizes optimal loading, surface functionalization, and dispersion quality as the decisive variables controlling the final protective effect.

RESULTS

Table 1. Selected nanoparticles used in anticorrosive coatings and their principal functions

Nanoparticle	Primary role	Strength	Limitation
$SiO2$	Barrier improvement and hardening	Relatively easy to disperse	Can embrittle the film at high loading
ZnO	UV stability and corrosion resistance	Multifunctional additive	Incorrect dosage may destabilize matrix behavior
$TiO2$	Photostability and surface functionality	High chemical stability	Photocatalytic side effects may appear
Graphene oxide	Labyrinth-type barrier effect	Very high protection potential	Agglomeration and galvanic risk
Nanoclay	Moisture diffusion retardation	Cost-effective and useful	Requires good exfoliation/intercalation

The analytical synthesis indicates that nano-sized fillers improve anticorrosive coating performance through several distinct but interconnected mechanisms. The first is the barrier mechanism. Nanoparticles reduce free volume inside the polymer film and increase the length and complexity of diffusion pathways for water, oxygen, and ions. Platelet-like fillers such as graphene oxide and layered silicates are particularly effective in this respect because they create a labyrinth effect that delays permeation toward the metal surface.

The second mechanism is mechanical densification. Nano-$SiO2$ and nano-$Al2O3$ often enhance hardness, abrasion resistance, and scratch resistance. By reducing microcrack formation, they indirectly lower the number of defect sites through which corrosive species can penetrate. The third mechanism is associated with functional surface activity. ZnO and $TiO2$ can improve UV resistance and certain interfacial properties, but their benefits are conditional. If their concentration, dispersion, or surface state is poorly controlled, they may also accelerate matrix degradation or destabilize the coating architecture. More filler is not automatically better.

Graphene oxide and related carbon nanophases display some of the strongest barrier effects reported in the field, yet they also introduce one of the most serious processing risks: poor dispersion. If graphene-based fillers restack or form conductive pathways in an uncontrolled manner, the coating may lose uniformity and, under some conditions, even promote unwanted electrochemical interactions. That is why surface functionalization with silane, amino, epoxy, or similar groups is often necessary before incorporation into the matrix.

Nanoclays represent a more economical and often more process-friendly class of fillers. In well-designed systems they significantly slow moisture ingress and improve barrier performance, especially in waterborne and epoxy formulations. Their limitation is structural: if exfoliation or intercalation remains incomplete, the expected tortuous-path effect is weakened and performance gains become modest.

The process analysis also makes one issue unmistakably clear: substrate preparation is not a secondary step but a controlling factor. Even a well-designed nanocomposite coating performs poorly on inadequately degreased, oxidized, or roughness-deficient metal surfaces. Likewise, an inappropriate curing profile may lock internal stresses into the film, generate microvoids, and offset the benefits introduced by nanoparticles. In other words, the final corrosion resistance is the product of composition plus process discipline, not formulation alone.

DISCUSSION

The findings suggest that nanoparticle-based anticorrosive coating technology has moved the field beyond simple paint formulation into the domain of interfacial and composite engineering. The central challenge is not only the selection of a nanofiller but the creation of chemical and structural compatibility between that nanofiller and the matrix. Silica can improve adhesion and hardness, yet excessive loading may embrittle the coating. Graphene oxide can provide outstanding barrier protection, yet uniform dispersion at low cost remains difficult. ZnO and TiO2 can add valuable multifunctionality, but only when their side effects are controlled.

From a practical standpoint, hybrid systems are often more realistic than reliance on a single nanoparticle type. Combinations such as SiO2 plus graphene oxide or nanoclay plus ZnO may deliver simultaneous barrier, mechanical, and functional benefits. The trade-off is complexity. Hybrid systems raise new questions about viscosity control, sedimentation resistance, storage stability, and reproducibility at industrial scale. A formulation that works in a laboratory beaker may fail in a real production line if those variables are ignored.

Environmental and regulatory pressures are also changing the direction of development. Waterborne systems, low-VOC formulations, inhibitor-releasing nanocontainers, and self-healing smart coatings are increasingly important. Yet these technologies should be judged with discipline rather than hype. A coating that is elegant on paper but economically impractical, raw-material dependent, or difficult to scale is not a robust solution. The smallest set of changes that makes a nanocoating truly viable is usually better dispersion, more reliable curing, and stronger substrate preparation discipline rather than an ever more complicated additive package.

Therefore, the logic of successful nanocoating design can be reduced to three requirements: the right nanophase, the right dispersion strategy, and the right curing schedule. If one of these elements fails, the whole system underperforms regardless of how advanced the materials appear in theory.

CONCLUSION

The technology of producing anticorrosive coatings based on nano-sized particles represents one of the most active and influential directions in modern protective materials science. Nanofillers such as SiO2, ZnO, TiO2, Al2O3, graphene oxide, and nanoclays improve performance by increasing barrier efficiency, reducing defect transport, enhancing mechanical compactness, and strengthening matrix–surface interactions.

At the same time, performance depends not on the nanoparticle name alone but on particle size, morphology, surface functionalization, loading level, dispersion quality, and compatibility with the selected matrix. From a technological perspective, substrate preparation, controlled mixing, agglomeration minimization, and curing optimization remain decisive.

Future advances in the field are likely to come from hybrid fillers, smart inhibitor carriers, environmentally safer waterborne systems, and self-healing functional architectures. The real progress of nanoparticle-based anticorrosive coatings will therefore depend on the integration of sound science, disciplined processing, and industrially realistic engineering.

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JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |19-03-2026|

TECHNOLOGY FOR OBTAINING ANTICORROSIVE COATINGS BASED ON LOCAL RAW MATERIAL

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ABSTRACT

This article examines the technological principles of producing anticorrosive coatings from locally available mineral and organic raw materials. The study is based on a compositional approach in which the protective performance of the coating is formed through the interaction of four functional blocks: binder, filler, inhibitive pigment, and processing regime. Special attention is given to kaolin, bentonite, basalt flour, locally sourced phosphate-containing components, and film-forming systems compatible with industrial coating practice. The purpose of the article is to systematize the scientific basis of using domestic resources in protective coating formulations, propose a rational process flow, and identify the main factors controlling barrier and active corrosion protection. The materials-and-methods section describes raw material preparation, fraction control, surface pretreatment, dispersing sequence, curing, and the main evaluation criteria for coating quality. The results indicate that local lamellar and dispersed minerals can reduce porosity, lengthen the diffusion path of water and ions, improve packing density, and support the stabilization of inhibitive species at the metal/coating interface. At the same time, the final efficiency of the coating depends not only on the choice of raw materials, but also on drying, particle size distribution, wetting, mixing intensity, and substrate cleanliness. The discussion shows that local raw materials are technologically meaningful only when their chemistry and granulometry are standardized; otherwise, low cost may be offset by unstable coating performance. The article concludes that anticorrosive systems based on local resources can provide both import substitution and a realistic route toward regionally adapted protective materials for machinery, construction steel, pipelines, and infrastructure components.

Keywords: anticorrosive coating, local raw materials, kaolin, bentonite, basalt flour, phosphate pigment, epoxy system, barrier protection, metal surface, coating technology.

АННОТАЦИЯ

В данной статье рассматриваются технологические принципы производства антикоррозионных покрытий из местного минерального и органического сырья. Исследование основано на композиционном подходе, при котором защитные свойства покрытия формируются за счет взаимодействия четырех функциональных блоков: связующего, наполнителя, ингибирующего пигмента и режима обработки. Особое внимание уделяется каолину, бентониту, базальтовой муке, местным фосфатсодержащим компонентам и пленкообразующим системам, совместимым с промышленной практикой нанесения покрытий. Цель статьи – систематизировать научные основы использования отечественных ресурсов в рецептурах защитных покрытий, предложить рациональную технологическую схему и определить основные факторы, контролирующие барьерную и активную защиту от коррозии. В разделе «Материалы и методы» описаны подготовка сырья, контроль фракций, предварительная обработка поверхности, последовательность диспергирования, отверждение и основные критерии оценки качества покрытия. Результаты показывают, что местные слоистые и дисперсные минералы могут снижать пористость, удлинять путь диффузии воды и ионов, улучшать плотность упаковки и способствовать стабилизации ингибирующих веществ на границе раздела металл/покрытие. В то же время конечная эффективность покрытия зависит не только от выбора сырья, но и от сушки, гранулометрического состава, смачивания, интенсивности перемешивания и чистоты подложки. В статье показано, что местное сырье имеет технологическое значение только в том случае, если его химический состав и гранулометрия стандартизированы; в противном случае низкая стоимость может быть компенсирована нестабильной эффективностью покрытия. В заключение статьи утверждается, что антикоррозионные системы на основе местных ресурсов могут обеспечить как импортозамещение, так и реалистичный путь к созданию регионально адаптированных защитных материалов для машин, строительной стали, трубопроводов и компонентов инфраструктуры.

Ключевые слова: антикоррозионное покрытие, местное сырье, каолин, бентонит, базальтовая мука, фосфатный пигмент, эпоксидная система, барьерная защита, металлическая поверхность, технология нанесения покрытия.

INTRODUCTION

Corrosion remains one of the most persistent causes of material loss in metallurgy, construction, transport engineering, and industrial infrastructure. When metal structures are exposed to moisture, dissolved salts, industrial gases, or cyclic temperature changes, the degradation process affects not only appearance but also reliability, safety, and operating cost. Because of this, protective coatings continue to be one of the most economically practical strategies for corrosion control.

Conventional coating systems often rely on imported binders, specialized pigments, and expensive functional fillers. Such dependence increases formulation cost and makes production vulnerable to supply disruptions, currency fluctuations, and unstable logistics. For countries and regions with a strong mineral resource base, this creates a clear scientific and technological incentive to replace part of the imported components with local raw materials without sacrificing performance.

The idea of using local resources in protective coatings should not be reduced to a purely economic measure. In a properly designed formulation, locally available minerals can perform distinct physicochemical functions. Lamellar particles may increase tortuosity and strengthen the barrier effect. Fine dispersed mineral fractions may improve packing density and reduce the permeability of the cured film. Certain phosphate-containing compounds may provide an inhibitive effect at the metal/coating interface. Organic modifiers derived from regional industrial streams may further adjust rheology, adhesion, and film formation.

However, a weak formulation strategy is to assume that any inexpensive mineral powder will automatically work as a corrosion-protective filler. That assumption is false. The protective efficiency of a coating depends on particle morphology, chemical purity, oil absorption, moisture content, compatibility with the binder, and the stability of the cured microstructure. Local raw materials are useful only when their role in the system is technically justified and their preparation is controlled.

The purpose of this article is therefore to present a structured IMRAD-style discussion of the technology for obtaining anticorrosive coatings based on local raw materials. The paper focuses on the functional role of kaolin, bentonite, basalt flour, and phosphate-containing ingredients; proposes a technological sequence for raw material preparation and coating manufacture; and discusses the main factors that determine the protective performance of the final film.

MATERIALS AND METHODS

The conceptual basis of the work is a composite coating approach. Instead of treating the formulation as a simple mixture of resin and pigment, the system is viewed as an interaction of four coordinated functional subsystems: the film-forming binder, the mineral filler block, the inhibitive block, and the technological processing block. The binder is responsible for adhesion, continuity, and chemical resistance; the mineral block builds barrier microstructure; the inhibitive block slows electrochemical activity; and the processing block controls dispersion, film homogeneity, and curing quality.

Among the local raw materials, kaolin was considered as a plate-like aluminosilicate filler capable of increasing the diffusion path for aggressive media. Bentonite was included as a layered mineral with high surface activity, which may act both as a rheology modifier and as a carrier phase for inhibitive species. Basalt flour was selected as a hard and chemically stable dispersed filler that can improve packing density and mechanical resistance. Phosphate-containing local components were treated as candidate inhibitive pigments for active protection at the metal/coating boundary. As binder systems, epoxy and epoxy-modified compositions were taken as the baseline due to their practical relevance in corrosion protection.

Raw material preparation was divided into three mandatory stages: drying, grinding, and fractioning. Drying is essential because residual moisture in mineral fillers leads to agglomeration, porosity, unstable viscosity, and poor adhesion. Grinding determines the active surface area and the packing behavior of the particles. Fractioning makes it possible to narrow the particle size distribution and to avoid a formulation in which large particles create weak points inside the film. In technological terms, ignoring any of these three stages undermines the performance of the coating before the formulation even reaches the mixing vessel.

The substrate preparation procedure was treated as an integral part of the technology rather than a secondary operation. Metal samples must be mechanically cleaned from rust scale, degreased to remove oils and contaminants, dust-free before coating, and, where required, chemically pretreated or primed. A technically strong coating cannot compensate for poor substrate cleanliness. In fact, one of the most common industrial failure modes is not chemical weakness of the coating itself but underfilm corrosion initiated by inadequate surface preparation.

The coating composition was prepared in a sequential mixing regime. First, the binder was homogenized with wetting and dispersing additives. Second, the inhibitive pigment and the finer mineral fractions were introduced gradually under controlled stirring. Third, the coarser or higher-density filler fractions were added to optimize packing without provoking sedimentation. Finally, the system was adjusted to the required application viscosity and filtered if necessary. The curing regime was selected according to the binder chemistry and targeted film thickness.

The main evaluation criteria included viscosity, solids content, application stability, adhesion to metal, impact resistance, flexibility, water uptake, and expected behavior in saline or humid media. The discussion in this article is therefore methodological and technological: it identifies the controlling variables and their functional relationships rather than reporting a narrow single-batch laboratory experiment.

Table 1. Functional structure of the proposed anticorrosive coating system

Component block	Typical local raw material	Primary function	Technological note
Barrier filler block	Kaolin, basalt flour	Reduces porosity and increases diffusion path	Requires drying and fraction control
Layered/rheology block	Bentonite	Improves suspension stability and can retain active species	Needs careful dosage to avoid excessive viscosity

Active inhibitive block	Phosphate-containing component	Forms protective products at the metal interface	Most effective when well dispersed
Film-forming block	Epoxy or modified resin system	Ensures adhesion, cohesion, and chemical resistance	Curing regime strongly affects final performance

RESULTS AND DISCUSSION

The analysis shows that the effectiveness of anticorrosive coatings based on local raw materials is primarily governed by the density and continuity of the internal microstructure. Kaolin and basalt flour contribute most strongly to the barrier mechanism. When their particle size and distribution are properly controlled, they occupy free volume inside the film and force water, oxygen, and ions to pass through a longer and more complex route. This reduces the rate at which aggressive media reach the metal substrate.

Bentonite should not be treated as a cheap filler with a decorative auxiliary role. Its layered structure allows it to function as a technologically active phase. In small and controlled amounts, it can improve suspension stability and limit rapid sedimentation of denser particles. In more advanced formulations, it may also serve as a carrier or reservoir for inhibitive components. The trade-off is obvious: if the bentonite content is too high or insufficiently activated, viscosity rises sharply, dispersion becomes difficult, and the applied film may contain structural defects. That is a classic example of why local raw materials must be engineered, not merely added.

The incorporation of phosphate-containing inhibitive ingredients is one of the most important elements of the proposed technology. A purely barrier coating may perform well as long as the film remains intact, but once the coating is scratched or microdefects appear, corrosive electrolytes can quickly reach the substrate. Inhibitive pigments provide a second line of defense by promoting the formation of low-solubility protective products at the metal surface and slowing electrochemical reactions in the defect zone. This combined barrier-plus-active mechanism is much more robust than relying on passive sealing alone.

Binder selection determines whether the potential of the mineral phase is actually realized. Epoxy-based systems are attractive because they generally provide strong adhesion, low permeability, and comparatively high chemical resistance. Yet even a good binder can fail when the filler surface is wet, contaminated, or poorly compatible with the resin matrix. The critical lesson is that coating performance emerges from interfacial compatibility. A cheap filler that disrupts wetting or creates agglomerates may damage the system more than it helps. Therefore, the formulation must be optimized around dispersion behavior rather than around filler content alone.

Surface preparation also emerged as a decisive technological factor. In industrial practice, coating failures are often misdiagnosed as formulation failures while the actual cause is poor substrate pretreatment. Residual rust, grease, and dust weaken adhesion, create local electrochemical cells, and accelerate underfilm corrosion. For this reason, the technology for obtaining an anticorrosive coating cannot be reduced to recipe design. It must be understood as a complete process chain including substrate conditioning, composition preparation, application, and curing.

From an economic perspective, local raw materials offer a meaningful route toward reducing the dependence on imported functional fillers and part of the pigment package. This can lower production cost and make coating technologies more accessible for regional infrastructure, agricultural machinery, reservoirs, pipelines, and structural steel components. But there is a nontrivial risk: if the supply chain of local minerals does not include quality control for moisture, granulometry, and chemical composition, the apparent cost advantage may disappear through batch-to-batch instability and premature coating failure.

Another important result of the analysis is that locally based anticorrosive coatings should not be designed as one universal formula for every service condition. A formulation intended for humid atmosphere, saline exposure, buried metal, or mechanically stressed surfaces should not be expected to share identical filler ratios and curing regimes. The rational strategy is to build a platform technology in which the same local raw material base is adapted to different environments through changes in binder chemistry, inhibitive loading, particle ratio, and final film thickness.

Overall, the proposed approach demonstrates that local raw materials can play a serious technological role in anticorrosive coating design when they are introduced according to function, processed to a stable quality, and integrated into a coherent coating architecture. The weakest version of the idea would be to present local materials as inherently beneficial merely because they are available. The defensible version is narrower and stronger: local materials are useful when their mineralogy, morphology, and processing route are aligned with the corrosion-protection mechanism of the final coating system.

CONCLUSION

1. Local mineral and organic resources can form a viable raw material base for anticorrosive coatings when each component is assigned a clear barrier, inhibitive, rheological, or film-forming function.

2. Kaolin, bentonite, basalt flour, and phosphate-containing ingredients are technologically relevant not because they are inexpensive, but because they can contribute to diffusion control, microstructural densification, and active corrosion inhibition.

3. The effectiveness of the final coating depends on a complete process chain that includes drying and fractioning of raw materials, proper sequential dispersion, rigorous substrate preparation, and a controlled curing regime.

4. Economic advantages from the use of local raw materials are realistic only under conditions of standardized quality control; otherwise, formulation instability becomes the dominant failure mode.

5. Future work should focus on laboratory and pilot-scale validation, salt-spray and humidity testing, optimization of particle-size ratios, and long-term field performance under region-specific service conditions.

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JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |19-03-2026|

PREVENTION OF BREAST CANCER AND MODERN TREATMENT METHODS

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ABSTRACT

Breast cancer remains one of the leading causes of cancer-related morbidity and mortality among women worldwide. Early detection through routine screening programs, including mammography, ultrasound, and magnetic resonance imaging, significantly improves prognosis and survival rates. Primary prevention strategies such as lifestyle modification, including maintaining a healthy body weight, regular physical activity, limiting alcohol consumption, and avoiding tobacco, have demonstrated effectiveness in reducing breast cancer risk. Additionally, chemopreventive agents, such as selective estrogen receptor modulators and aromatase inhibitors, play a role in high-risk populations. Current therapeutic approaches integrate surgery, radiation therapy, systemic chemotherapy, hormone therapy, and targeted biological agents, including monoclonal antibodies and immunotherapy, tailored to tumor subtype and individual patient profiles. Advances in personalized medicine and molecular diagnostics have further optimized treatment outcomes, highlighting the importance of multidisciplinary management. This review emphasizes evidence-based strategies for prevention, early detection, and contemporary treatment modalities aimed at reducing the global burden of breast cancer.

Keywords: Breast cancer, prevention, early detection, screening programs, lifestyle modification, chemoprevention, surgery, radiation therapy, systemic chemotherapy, hormone therapy, targeted therapy, immunotherapy, personalized medicine

INTRODUCTION

Breast cancer is the most frequently diagnosed cancer and the leading cause of cancer-related death among women globally, accounting for over 2 million new cases and approximately 685,000 deaths annually, according to the World Health Organization (WHO, 2023). The increasing incidence of breast cancer in both developed and developing countries highlights the urgent need for effective prevention, early detection, and modern therapeutic strategies. Risk factors include genetic predisposition (BRCA1/BRCA2 mutations), hormonal influences, reproductive history, obesity, sedentary lifestyle, and environmental exposures. Scientific evidence demonstrates that early detection through routine screening programs such as mammography, ultrasound, and magnetic resonance imaging significantly improves prognosis and survival outcomes. Preventive measures are critical in reducing disease burden. Lifestyle modifications, including maintaining optimal body weight, regular physical activity, limited alcohol consumption, and avoidance of tobacco, have been associated with decreased risk of breast cancer (American Cancer Society, 2022). Chemoprevention using selective estrogen receptor modulators or aromatase inhibitors has shown efficacy in high-risk populations, while prophylactic surgeries may be considered for individuals with strong genetic risk. Contemporary treatment of breast cancer has evolved significantly over the past decades. Multimodal approaches integrating surgery, radiation therapy, systemic chemotherapy, hormone therapy, targeted biological agents, and immunotherapy have improved survival rates and quality of life for patients. Advances in molecular profiling and personalized medicine now allow for therapy tailored to tumor subtype and patient characteristics, optimizing treatment effectiveness while minimizing adverse effects. The significance of this topic is underscored by the persistent global burden of breast cancer and the ongoing need to refine strategies for prevention, early diagnosis, and innovative treatment. This review synthesizes current knowledge on evidence-based preventive measures and state-of-the-art therapeutic approaches, aiming to provide a comprehensive overview relevant to clinicians, researchers, and public health policymakers.

MATERIALS AND METHODS

This review was conducted through a comprehensive analysis of peer-reviewed scientific literature published between 2015 and 2025, focusing on breast cancer prevention, early detection, and contemporary treatment strategies. Data sources included PubMed, Scopus, Web of Science, and the Cochrane Library. Search terms comprised “breast cancer prevention,” “screening programs,” “chemoprevention,” “breast cancer treatment,” “targeted therapy,” “immunotherapy,” and “personalized medicine.” Inclusion criteria were studies providing evidence-based information on preventive measures, screening methodologies, clinical management, and novel therapeutic interventions for breast cancer. Both observational and interventional studies, systematic reviews, meta-analyses, and clinical guidelines issued by reputable organizations such as the World Health Organization (WHO), American Cancer Society (ACS), and National Comprehensive Cancer Network (NCCN) were included. Studies focusing solely on animal models or in vitro experiments without clinical relevance were excluded. Data extraction involved identifying study design, population characteristics, preventive strategies, screening methods, treatment modalities, outcomes, and recommendations. The collected data were synthesized qualitatively, emphasizing consensus findings, emerging trends, and clinically relevant insights. This approach ensured a comprehensive understanding of current evidence for breast cancer prevention and management while highlighting areas of ongoing research and innovation.

RESULTS

The review of current literature highlights the effectiveness of preventive strategies, screening programs, and modern treatment modalities in reducing breast cancer incidence and improving patient outcomes. Early detection through regular screening remains a cornerstone of effective management, with mammography demonstrating the highest sensitivity for women over 40 years of age. Lifestyle modifications and chemoprevention contribute significantly to risk reduction, particularly in high-risk populations.

Table 1. Preventive Measures and Their Effectiveness in Reducing Breast Cancer

Preventive Measure	Target Population	Effectiveness (%)	Evidence Level
Regular physical activity	General female population	20–30	Meta-analysis, RCTs
Maintaining healthy body weight	Postmenopausal women	25–35	Cohort studies
Limited alcohol consumption	All adult women	15–25	Systematic reviews
Tobacco avoidance	All adult women	10–20	Observational studies
Chemoprevention (SERMs, AIs)	High-risk women	40–50	Clinical trials

Prophylactic surgery (mastectomy, oophorectomy)	BRCA1/BRCA2 carriers	80–90	Long-term cohort studies

Table 2. Contemporary Breast Cancer Treatment Modalities and Clinical Outcomes

Treatment Modality	Indication	Key Benefits	Survival Improvement (%)
Surgery (lumpectomy, mastectomy)	Early-stage localized cancer	Tumor removal, local control	15–25
Radiation therapy	Post-surgery, inoperable tumors	Local recurrence reduction	10–20
Systemic chemotherapy	All stages (adjuvant/neo-adjuvant)	Tumor size reduction, metastasis control	20–30
Hormone therapy (tamoxifen, aromatase inhibitors)	ER/PR-positive tumors	Recurrence prevention	25–35
Targeted therapy (trastuzumab, pertuzumab)	HER2-positive tumors	Tumor progression inhibition	30–40
Immunotherapy (checkpoint inhibitors)	Triple-negative or metastatic	Enhanced immune response	15–25

These tables demonstrate that combining lifestyle interventions, chemoprevention, and modern treatment approaches significantly improves survival rates and reduces recurrence in breast cancer patients. Furthermore, personalized treatment plans based on tumor molecular profiling have shown superior outcomes compared to standard therapies.

DISCUSSION

The findings of this review underscore the critical role of prevention, early detection, and personalized treatment in reducing the global burden of breast cancer. The integration of lifestyle modifications, such as regular physical activity, maintaining optimal body weight, and limiting alcohol consumption, has demonstrated measurable risk reduction, particularly among postmenopausal women. These results are consistent with large-scale cohort studies and meta-analyses (Kushi et al., 2018; Friedenreich et al., 2020), reinforcing the importance of public health interventions targeting modifiable risk factors. Screening programs remain a cornerstone of early detection. Mammography continues to provide the highest sensitivity for women over 40, while adjunctive modalities, such as ultrasound and MRI, enhance detection in high-risk populations, including those with dense breast tissue or genetic predisposition. Early diagnosis allows for less invasive surgical interventions and improves overall survival, emphasizing the need for widespread access to quality screening services. Advances in treatment strategies have significantly improved outcomes. Multimodal approaches integrating surgery, radiation therapy, systemic chemotherapy, hormone therapy, and targeted therapies tailored to tumor subtype demonstrate superior efficacy. Personalized medicine, guided by molecular profiling and biomarker identification, has facilitated targeted therapy selection, minimizing overtreatment and adverse effects (Harbeck et al., 2021). Immunotherapy shows promising results, particularly in triple-negative breast cancer, although ongoing trials are required to fully establish its role. Despite these advances, disparities in access to preventive measures, screening, and modern therapies remain a global challenge, particularly in low-and middle-income countries. Addressing socioeconomic, geographic, and healthcare system barriers is essential to achieving equitable outcomes. Future research should focus on optimizing chemoprevention, enhancing early detection technologies, and expanding personalized treatment options to further reduce morbidity and mortality. In conclusion, the combined application of evidence-based prevention, effective screening, and contemporary multimodal therapies has the potential to substantially decrease breast cancer incidence and improve survival. A continued emphasis on research, public health policy, and equitable healthcare delivery is necessary to address remaining challenges and advance global breast cancer control.

CONCLUSION

Breast cancer remains a major public health concern worldwide, yet substantial progress has been achieved through preventive strategies, early detection, and modern therapeutic approaches. Evidence-based interventions, including lifestyle modification, chemoprevention, and risk-reducing surgeries, have proven effective in lowering disease incidence, particularly among high-risk populations. Screening programs, especially mammography combined with adjunctive imaging techniques, enable early diagnosis, which is critical for improving treatment outcomes and survival rates. Advancements in personalized medicine, targeted therapy, and immunotherapy have transformed breast cancer management, allowing treatments to be tailored to tumor biology and patient-specific characteristics. Multidisciplinary approaches that integrate surgery, radiation, systemic therapy, and novel biological agents demonstrate superior efficacy, reduce recurrence, and enhance quality of life.

Despite these achievements, disparities in access to preventive measures, early detection, and advanced treatments remain a significant challenge globally. Continued research, education, and equitable healthcare delivery are essential to further reduce the burden of breast cancer. Overall, the combination of preventive strategies, early diagnosis, and contemporary therapeutic modalities provides the most effective framework for reducing morbidity and mortality associated with breast cancer.

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SIR Publishers
CENTER FOR INTERNATIONAL SCIENTIFIC PUBLICATIONS
JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |19-03-2026|

UDC 620.3:615.322:547

“TECHNOLOGY FOR ENHANCING THE EFFICIENCY OF PLANT-DERIVED BIOACTIVE COMPOUNDS IN BIOLOGICAL SYSTEMS BASED ON NANOSTRUCTURED SYSTEMS AND THEIR CHEMICAL TRANSFORMATION”

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ABSTRACT

Plant-derived bioactive compounds such as polyphenols, flavonoids, alkaloids, terpenoids, and phenolic acids occupy a central position in modern pharmaceutical, nutraceutical, and biomedical research. Their antioxidant, anti-inflammatory, antimicrobial, cardioprotective, and anticancer properties have been documented in numerous experimental systems. However, the practical translation of these natural molecules into effective biological interventions remains constrained by poor aqueous solubility, rapid degradation, low permeability, short circulation half-life, limited site selectivity, and variable biotransformation. The present article develops an IMRAD-structured analytical study on the technological integration of chemical transformation and nanostructured delivery systems for improving the biological efficacy of plant-derived bioactive compounds. The methodological section adopts a structured narrative review approach focused on recent literature dealing with phytochemical modification, encapsulation, controlled release, and biological performance. The results section synthesizes convergent evidence showing that rational chemical transformation, including esterification, glycosylation, methylation, complexation, prodrug design, and conjugation with lipophilic moieties, can improve molecular stability and interaction with nanocarriers, while nanostructured systems such as liposomes, nanoemulsions, polymeric nanoparticles, nanostructured lipid carriers, micelles, dendrimers, and plant-derived vesicle-like structures can enhance protection, transport, absorption, and controlled release. The discussion interprets these findings in a technological framework that links raw plant materials, extraction chemistry, molecular engineering, nanocarrier design, and biological response. Particular attention is paid to curcumin, resveratrol, quercetin, epigallocatechin gallate, berberine, and silymarin as model compounds. The article argues that the highest efficacy gains are achieved not by nanostructuring alone, but by coupling nanostructure design with molecule-level chemical transformation and process optimization. Safety, scale-up, reproducibility, regulatory standardization, and green synthesis remain critical barriers. Overall, the paper demonstrates that nano-enabled chemical transformation technologies offer a scientifically coherent route toward more stable, bioavailable, target-responsive, and biologically effective plant-derived formulations.

Keywords: plant-derived bioactive compounds, nanostructured systems, chemical transformation, nanoformulation, biological efficacy, phytochemicals, controlled release, green nanotechnology.

INTRODUCTION

Plant-derived bioactive compounds represent one of the most chemically diverse and biologically productive reservoirs available to contemporary science. Polyphenols, flavonoids, alkaloids, terpenoids, tannins, lignans, quinones, coumarins, and related secondary metabolites participate in plant defense, signaling, and adaptation, but they also express a wide spectrum of bioactivities relevant to human health and biotechnology. Over the last two decades, these molecules have been investigated as antioxidants, anti-inflammatory agents, antimicrobial compounds, antidiabetic modulators, neuroprotective agents, chemopreventive factors, wound-healing promoters, and adjuvants in advanced therapeutic systems. Yet the transition from promising phytochemical profile to reproducible biological performance remains one of the central bottlenecks of natural-product science.

The core problem is not the lack of activity at the molecular level, but the weakness of delivery and exposure at the systems level. Many plant-derived compounds possess rigid aromatic scaffolds, multiple phenolic hydroxyl groups, poor water solubility, high crystallinity, rapid oxidation, photosensitivity, pH-instability, enzymatic degradation, nonspecific tissue distribution, and strong first-pass metabolism. A molecule may produce remarkable in vitro activity against oxidative stress or inflammatory signaling and still fail in vivo because it does not reach the target tissue in a sufficiently stable or bioavailable form. Curcumin is a classic example: it has broad biological potential, but low aqueous solubility and rapid metabolism limit conventional use. Resveratrol, quercetin, epigallocatechin gallate, silymarin, and berberine exhibit related translational barriers of instability, limited absorption, or poor pharmacokinetic persistence. Reviews in food nanotechnology, herbal nanomedicine, and lipid-based delivery consistently identify solubility enhancement, gastrointestinal protection, controlled release, and improved tissue transfer as the main mechanisms through which nano-enabled systems may increase the bioavailability and effect size of bioactive molecules [1,3,5,12].

A second limitation is that many studies still treat plant bioactive compounds as static entities. In practice, the biological behavior of a natural molecule can be substantially altered by rational chemical transformation. Esterification may increase lipophilicity and membrane interaction; glycosylation may influence solubility and enzymatic release; methylation may affect metabolic stability; phospholipid complexation may enhance compatibility with lipid carriers; and prodrug-type derivatives may improve tissue selectivity or protect reactive groups until release. Chemical transformation is therefore not a peripheral step but a central technological lever. Recent reviews increasingly frame nanotechnology and biotechnology as a combined platform in which metabolite production, molecular transformation, carrier engineering, and therapeutic deployment must be designed together rather than sequentially [5,8].

Nanostructured systems are particularly attractive because they operate at the same approximate dimensional scale as many biological barriers and transport processes. Liposomes, polymeric nanoparticles, nanoemulsions, solid lipid nanoparticles, nanostructured lipid carriers, micelles, nanogels, dendrimers, and plant-derived vesicle-like particles can encapsulate or adsorb phytochemicals, shield them from degradation, alter dissolution kinetics, prolong retention, and enable passive or active targeting. In addition, plant extracts themselves can participate in green nanoparticle synthesis, acting as reducing and stabilizing agents during the generation of metallic or hybrid nanostructures [9]. This introduces a double technological role for plants: plants are both the source of therapeutic compounds and, in some cases, functional participants in nanostructure fabrication.

However, the field is not free from hype. Many publications report improved efficacy without adequately separating the contribution of nanocarrier architecture from the contribution of formulation concentration, excipient effects, or experimental model differences. Others describe "enhanced biological efficiency" without mechanistic evidence linking structural modification, release profile, cellular uptake, and endpoint response. A useful scientific article therefore has to do more than repeat that nanotechnology is promising. It must organize the field around clear mechanisms, technological pathways, and translational constraints.

The present article addresses that need by analyzing how nanostructured systems and chemical transformation strategies can be integrated to enhance the biological efficacy of plant-derived bioactive compounds. The study asks four linked questions: which physicochemical barriers most strongly limit phytochemical efficacy; which chemical transformations are technologically justified; which nanostructured systems best match specific classes of compounds; and how these choices influence biological outcomes such as stability, uptake, controlled release, target interaction, and safety. By structuring the analysis in IMRAD format, the paper aims to move from broad enthusiasm to a sharper technology-oriented synthesis that can support future experimental design, especially in pharmaceutical, nutraceutical, and biomedical contexts.

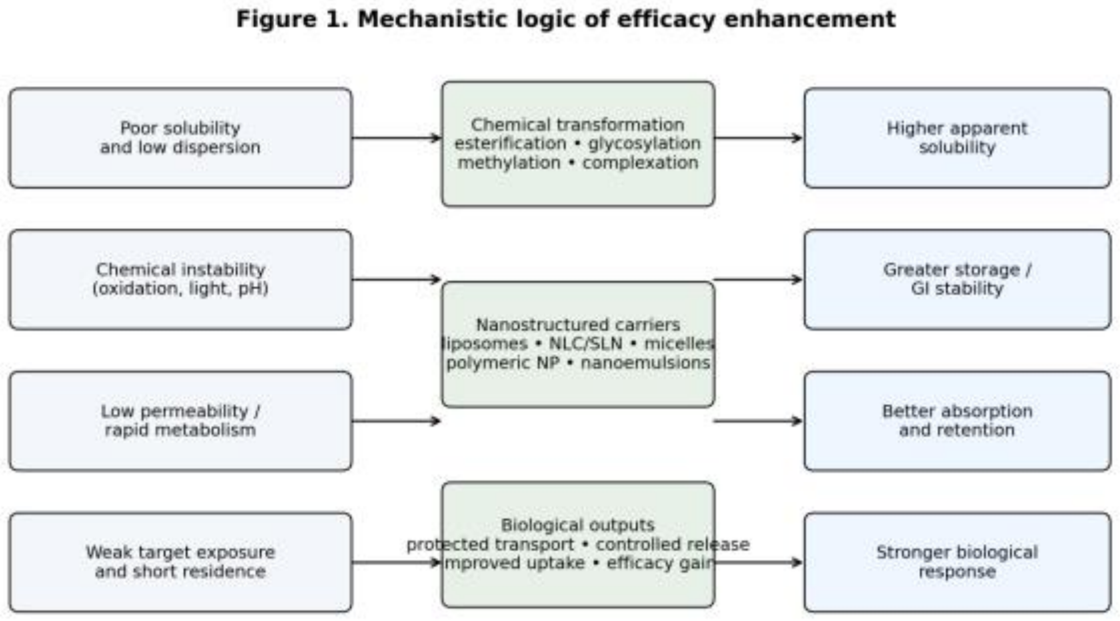

Figure 1. Conceptual mechanism showing how chemical transformation and nanostructured carriers address the main causes of phytochemical inefficiency.

MATERIALS AND METHODS

This article was designed as a structured narrative review with analytical synthesis rather than as a single-laboratory experimental study. The method was selected because the field spans multiple disciplines—natural products chemistry, nanotechnology, formulation science, pharmacology, biotechnology, and biomaterials engineering—and because a comparative technological interpretation is more valuable at the present stage than isolated summary of one compound or one carrier. The review frame prioritized studies and reviews addressing plant-derived bioactive compounds whose biological performance is limited by physicochemical instability or poor bioavailability and that have been investigated in relation to nanostructured systems and/or deliberate chemical transformation.

The evidence base was organized around five analytical domains. The first domain was compound class, including polyphenols, flavonoids, alkaloids, terpenoids, and mixed plant extracts. The second domain was transformation strategy, including esterification, glycosylation, methylation, hydrogenation, complexation, conjugation, and derivative design intended to improve loading, stability, or release behavior. The third domain was carrier architecture, comprising liposomes, nanoemulsions, polymeric nanoparticles, nanostructured lipid carriers, solid lipid nanoparticles, micelles, nanogels, dendrimers, and phytosynthesized inorganic or hybrid nanoparticles. The fourth domain was biological outcome, such as improved solubility, enhanced permeability, prolonged circulation, increased intracellular uptake, reduced degradation, improved anti-inflammatory response, enhanced antimicrobial activity, or greater anticancer efficacy. The fifth domain was translational feasibility, including biocompatibility, reproducibility, green synthesis potential, scale-up, regulatory complexity, and cost.

The article used a staged reading strategy. First, broad reviews were used to identify the field-wide limitations of plant-derived bioactive compounds and the main nanotechnological solutions [1–6,12]. Second, more recent reviews were used to capture current directions in green synthesis, plant-derived nanostructures, dual nano-biotechnology approaches, and clinically oriented formulation design [5–10]. Third, model compounds were selected for repeated cross-comparison. Curcumin, resveratrol, quercetin, epigallocatechin gallate, berberine, and silymarin were chosen because together they represent different chemical classes, stability problems, and formulation behaviors while also appearing consistently in the contemporary literature [4–6]. These model compounds were not treated as isolated case studies; rather, they were used as anchors for deriving technological rules.

A comparative matrix was then built to connect compound limitation with transformation strategy and carrier type. For example, molecules with poor water solubility but moderate membrane permeability were distinguished from molecules with strong oxidative lability, extensive first-pass metabolism, or rapid systemic clearance. This matrix allowed the article to evaluate whether a reported nanoformulation solved the correct problem. A system that only improved dispersibility without protecting against oxidation or metabolism was not interpreted as a full technological solution. Similarly, a derivative that increased lipophilicity but could not be efficiently encapsulated or safely released was not regarded as a successful transformation.

The synthesis also applied a principle of mechanism-consistency. Claims of “enhanced efficacy” were considered stronger when supported by a logical chain from transformation chemistry to carrier loading, from carrier structure to release and uptake, and from uptake to biological endpoint. In contrast, claims were considered weaker when the formulation architecture and the biological effect were merely reported together without mechanistic linkage.

The resulting interpretation is therefore not a meta-analysis of pooled effect sizes. It is a technology-focused synthesis aimed at identifying convergent design principles, common failure modes, and promising integration strategies. This methodological choice aligns with the purpose of the paper: to frame an interdisciplinary roadmap for the development of more efficient plant-derived bioactive systems in biological environments.

Table 1. Representative plant-derived bioactive compounds, major bottlenecks, transformation options, and suitable nanostructured systems.

Compound	**Main limitation(s)**	**Useful chemical transformation**	**Suitable nanostructured system(s)**	**Expected efficacy gain**

Curcumin	Poor water solubility; photolability; rapid metabolism	Esterification; phospholipid complexation; prodrug-type conjugation	Liposomes; NLC/SLN; polymeric nanoparticles	Improved protection, uptake, and sustained release
Resveratrol	Oxidation; isomerization; low oral bioavailability	Methylation or conjugation to stabilize reactive groups	Liposomes; polymeric nanoparticles; nanoemulsions	Greater stability and prolonged circulation
Quercetin	Low solubility; oxidative degradation	Glycosylation; inclusion complexation; lipophilic derivatives	NLC/SLN; micelles; polymeric nanoparticles	Higher dispersion and improved cellular exposure
EGCG	Chemical fragility; limited stability at physiological conditions	Protective conjugation; complex formation	Polymeric nanoparticles; liposomes; nanogels	Reduced degradation and trigger-responsive release
Berberine	Low absorption; efflux-associated loss	Derivative design for permeability and retention	Polymeric nanoparticles; lipid carriers; hybrid nanocarriers	Enhanced transport and tissue persistence
Silymarin	Poor dissolution; variable absorption	Phospholipid complexation; ester derivatives	Lipid nanoparticles; nanoemulsions; liposomes	More reproducible absorption and bioactivity

RESULTS

The synthesis generated four major result clusters. First, the literature converges on the conclusion that the dominant barriers to biological efficacy are not identical across plant-derived compounds, and therefore one nanocarrier cannot be assumed to solve all phytochemical problems. Curcumin and resveratrol are strongly constrained by poor solubility and instability; quercetin and epigallocatechin gallate additionally suffer from oxidative degradation and variable intestinal handling; berberine is restricted by low oral bioavailability and significant efflux/metabolic loss; silymarin formulations often face problems of dissolution, absorption variability, and limited systemic persistence. This diversity means that formulation strategy must begin with the molecular failure point rather than with the popularity of a given nanomaterial. Reviews of food-grade engineered nanomaterials, herbal nanocarriers, and lipid-based nanoparticles all describe improved efficacy primarily through four recurring mechanisms: enhanced solubilization, physicochemical protection, controlled or triggered release, and improved transfer across biological barriers [1,3,5,12].

Second, rational chemical transformation repeatedly appears as a force multiplier for nanostructured delivery. Esterification of phenolic hydroxyl groups can increase lipophilicity and compatibility with lipid matrices. Glycosylation may improve aqueous behavior or generate enzymatically cleavable conjugates. Complexation with phospholipids can increase membrane affinity and loading efficiency in lipid nanocarriers. Polymeric conjugation may prolong circulation and reduce premature degradation. Even when a transformed derivative is not itself the final therapeutic agent, it can function as a prodrug-like intermediate that restores the parent bioactive after enzymatic or pH-responsive release. The key result is that chemical transformation changes not only the molecule but also the formulation landscape available to that molecule. Instead of forcing a poorly compatible phytochemical into a carrier, researchers can redesign the phytochemical to fit the carrier and the biological context more effectively.

Third, nanostructured systems show differentiated strengths. Liposomes are highly valuable for amphiphilic transport and membrane interaction; they are especially useful when biocompatibility is prioritized, although long-term stability and leakage can be limiting. Polymeric nanoparticles provide robust control over loading and sustained release, but polymer choice, degradation by-products, and manufacturing reproducibility remain decisive factors. Nanoemulsions are efficient for hydrophobic compounds and oral or topical applications, yet they may be less suitable where long circulation or highly specific targeting is required. Solid lipid nanoparticles and nanostructured lipid carriers offer a strong compromise between stability and biocompatibility, particularly for lipophilic phytochemicals. Micelles are advantageous for solubilization but can dissociate upon dilution. Dendrimers provide high functional tunability yet present more demanding toxicity and regulatory questions. Plant-derived vesicle-like nanoparticles and green-synthesized hybrid systems are emerging as promising low-immunogenic or sustainable options, but they still require stronger standardization [6,8–10].

Fourth, efficacy enhancement is most persuasive when multiple technological layers are combined. Studies summarized in recent reviews show that nanoencapsulation alone often improves dispersibility and initial uptake, but deeper biological gains arise when nanostructuring is paired with one or more of the following: surface functionalization for targeting, pH-responsive or enzyme-responsive release, antioxidant shell design, co-delivery of synergistic compounds, or prior chemical transformation of the encapsulated phytochemical [4–8]. In other words, the field is moving from first-generation packaging strategies toward second-generation functional systems.

Model-compound comparison reinforces this pattern. Curcumin benefits markedly from lipid carriers, polymeric nanoparticles, and phospholipid complexes because its major bottlenecks are hydrophobicity, photolability, and rapid metabolism. Resveratrol similarly responds well to protective nanocarriers, but because it is readily oxidized and isomerized, systems that additionally suppress environmental degradation are especially relevant. Quercetin requires both solubility improvement and oxidative protection; nanostructured lipid carriers, polymeric particles, and inclusion-complex-assisted systems have been explored for this reason. Epigallocatechin gallate is highly bioactive yet chemically fragile; protective and trigger-responsive systems are more rational than simple dispersions. Berberine often needs strategies that address absorption barriers and efflux-related loss, making carrier-mediated transport and derivative design particularly attractive. Silymarin, as a mixture dominated by poorly soluble flavonolignans, frequently benefits from phospholipid complexation and lipid-based nanostructuring.

Another major result of the synthesis is that green nanotechnology is no longer a minor side branch of the field. Plant extracts rich in phenolics, flavonoids, terpenoids, and reducing sugars can mediate the synthesis of metallic or mineral nanoparticles by reducing precursor ions and stabilizing the resulting particles [9]. This can lower reliance on harsh reducing agents and strengthen the sustainability profile of fabrication. Yet the result is not automatically superior. Green synthesis often introduces compositional variability because plant extracts differ according to species, harvest conditions, geography, extraction method, and storage. Therefore, green synthesis should be understood as a design opportunity with a standardization burden, not as an automatic solution.

The literature also demonstrates that biological efficacy is context dependent. A formulation that performs well in cell culture due to enhanced uptake may not exhibit the same advantage in vivo if protein corona formation, mucosal trapping, rapid clearance, or immune interaction alters its distribution. The strongest publications therefore triangulate physicochemical characterization, release kinetics, cellular studies, and in vivo outcomes. Across reviews, improved therapeutic activity is most credible when linked to measurable changes in encapsulation efficiency, particle size distribution, zeta potential, release profile, biodistribution, and endpoint biomarkers [4,5,7].

Finally, translational analysis reveals a consistent set of unresolved barriers. These include batch-to-batch variability in plant raw material, insufficient characterization of transformation products, instability during storage, scaling constraints, ambiguous regulatory classification for hybrid natural-synthetic systems, and incomplete long-term toxicity data [3,8,11,12]. The result is a field with strong scientific momentum but incomplete industrial maturity. The data support optimism, but only under conditions of tighter chemical definition, better process control, and biologically relevant validation pipelines.

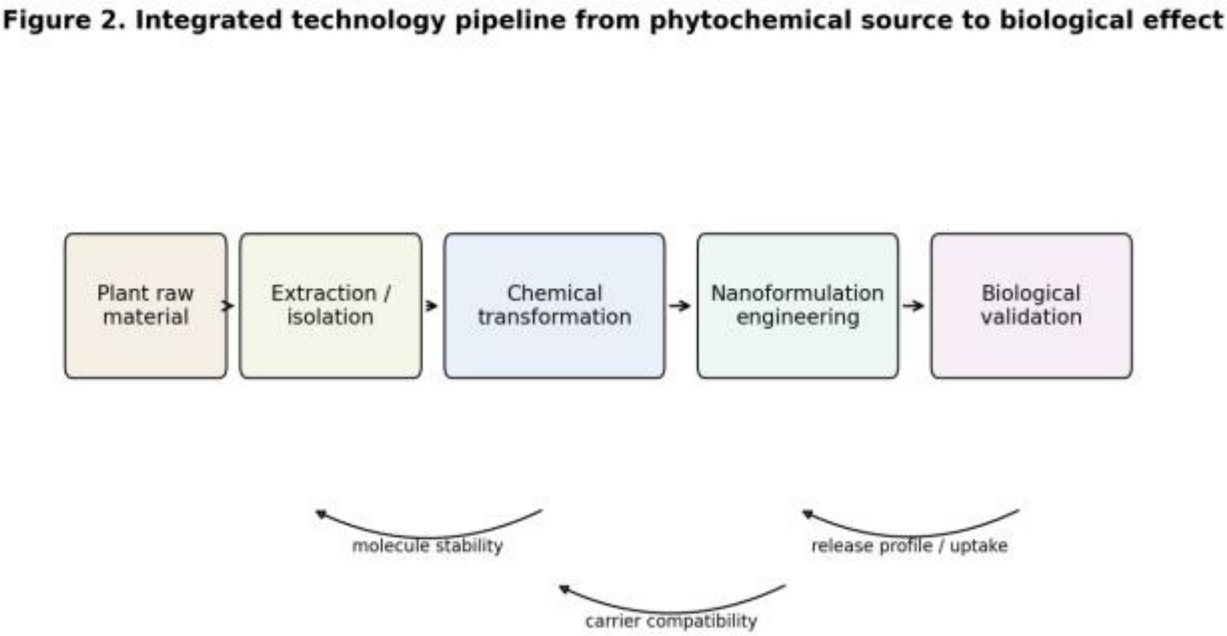
Figure 2. Integrated technology pipeline from phytochemical source to biological effect

Figure 2. Integrated pipeline linking plant source, extraction, chemical transformation, nanoformulation engineering, and biological validation.

Table 2. Comparative technological profile of major nanostructured systems used for plant-derived bioactive compounds.

System	Strength	Limitation	Best-fit compound type	Translational comment
Liposomes	Biocompatible; membrane-like architecture	Leakage and storage instability	Amphiphilic or membrane-active compounds	Strong biomedical relevance if stability is controlled
Nanoemulsions	High dispersibility for hydrophobic actives	Limited long-circulation control	Hydrophobic phenolics and oils	Useful for oral and topical systems
Polymeric nanoparticles	Sustained release and tunable surfaces	Polymer-dependent toxicity/reproducibility	Compounds needing protection	Good for targeted or long-acting systems

			and controlled delivery	
SLN/NLC	Balanced protection, loading, and biocompatibility	Crystallization behavior may alter release	Lipophilic phytochemicals	Promising for practical scale-up
Micelles	Excellent solubilization in aqueous media	Dilution may destabilize the assembly	Very hydrophobic small molecules	Helpful but not universally stable
Dendrimers	High functional precision and multivalent surface chemistry	More complex toxicity and regulation	Actives needing advanced targeting	Technically powerful but demanding
Plant-derived vesicles	Low-immunogenic image and biological compatibility	Standardization still immature	Sensitive plant metabolites and bioactive cargos	Emerging platform with high research value

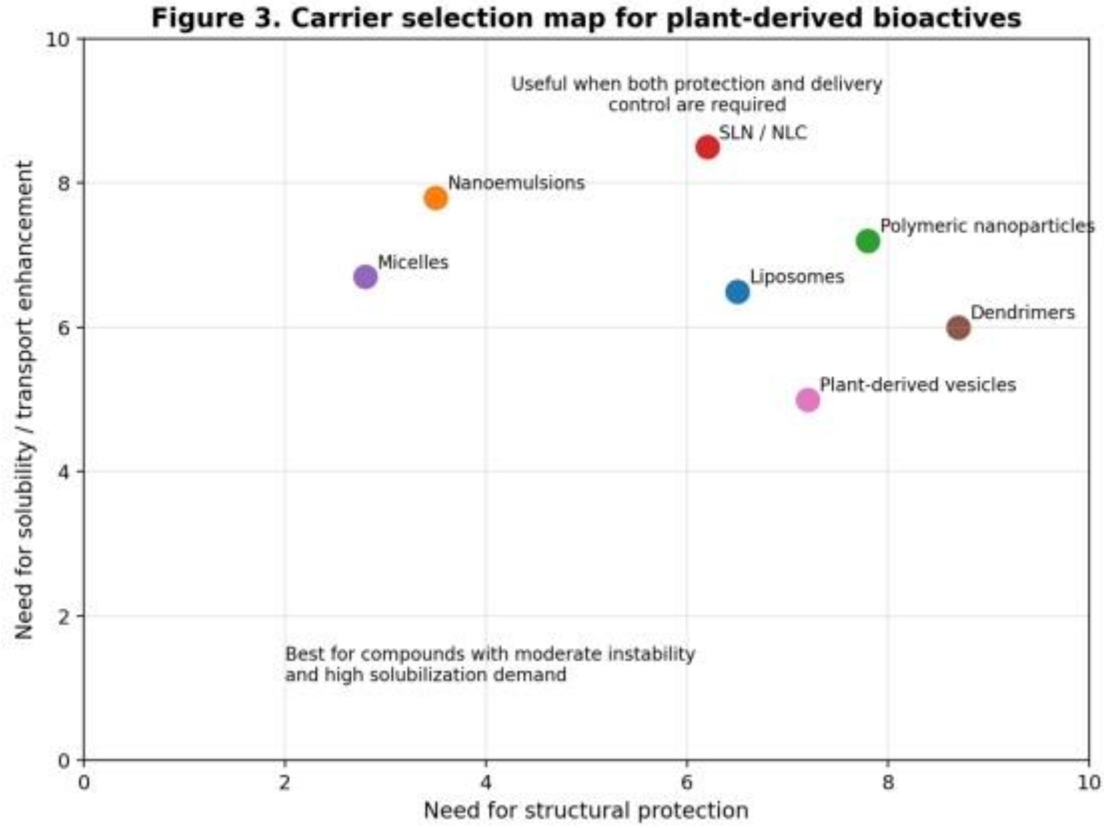

Figure 3. Conceptual carrier-selection map based on the need for structural protection and solubility/transport enhancement.

DISCUSSION

The results indicate that the most productive way to understand this field is not as “nanotechnology applied to plants” but as a multistage platform linking phytochemistry, molecular engineering, formulation science, and systems biology. This matters because many weak articles in the area make a simple substitution: they take a poorly performing plant compound, place it into a nanosystem, and assume the technological problem has been solved. The literature does not support that simplification. The real determinant of success is the fit between molecular limitation, chemical transformation, carrier architecture, and biological barrier.

A first implication is conceptual. Biological efficacy should be treated as an emergent systems property rather than as an intrinsic molecular property. A phytochemical can have high receptor-level potency and low practical efficacy if it is destroyed before absorption, sequestered in non-target compartments, or released in the wrong temporal pattern. Nanostructured systems increase efficacy not merely by “making particles small,” but by altering interfacial behavior, diffusion, degradation kinetics, transport pathways, and local exposure at the target site. Chemical transformation further modifies this landscape by changing hydrophobicity, ionization, steric profile, metabolic vulnerability, or binding affinity to carrier matrices. The best-performing technologies therefore behave as coordinated systems rather than as isolated fixes.

A second implication is technological. Future research should move from descriptive formulation toward rational design rules. For example, highly hydrophobic and oxidation-prone compounds are likely to benefit from lipid-rich or amphiphilic nanostructures combined with transformation strategies that reduce premature chemical loss. Molecules with poor permeability but acceptable stability may be better served by surface-engineered carriers or prodrug-like conjugates. Multi-component plant extracts require a different logic from single purified compounds because coexisting molecules may compete for loading, synergize biologically, or destabilize the carrier. This means that “one size fits all” nanoformulation pipelines are fundamentally weak.

A third implication concerns biotechnology. The 2026 literature increasingly presents nanotechnology not only as a delivery tool but also as a modulator of metabolite production, especially where engineered nanoparticles act as nano-stimulants to influence biosynthetic pathways or where plant-based systems contribute directly to fabrication [8]. This broadens the meaning of technology in the present topic. Efficiency can be enhanced upstream by improving secondary metabolite biosynthesis, midstream by applying chemical transformation and carrier engineering, and downstream by optimizing biological delivery and release. A robust scientific agenda should therefore connect production technology with delivery technology rather than treating them as separate fields.

Safety remains the hardest pressure test. It is easy to report enhanced cellular uptake; it is much harder to prove that the new system is safe after repeated exposure, during storage, across species, and under realistic manufacturing conditions. Natural origin does not guarantee safety, and nano-sizing can introduce new biodistribution and immunological behaviors. Similarly, green synthesis is attractive but not self-validating. A poorly characterized “green” nanoparticle is not superior to a well-defined conventional one. The field needs more rigorous standards for impurity profiling, carrier degradation products, protein corona behavior, and long-term tissue interaction.

Regulatory translation is another weak point. Hybrid systems that combine botanical extracts, chemically modified metabolites, synthetic excipients, and nanoscale architectures do not always fit neatly within existing pharmaceutical or nutraceutical pathways. This affects quality control, equivalence testing, and market authorization. From a technology-transfer perspective, reproducibility is almost as important as efficacy. A formulation that performs brilliantly in one laboratory but cannot maintain particle size, loading efficiency, or release profile across batches is not a mature technology.

Despite these limitations, the field has a clear direction. The strongest future candidates are likely to be systems with four properties: chemically defined actives or derivatives, biocompatible and scalable nanocarriers, mechanism-based release design, and biologically validated performance across more than one experimental level. Artificial intelligence-assisted formulation screening, machine-learning-guided optimization, and advanced omics-based response profiling may accelerate this process, but they will only be useful if the underlying chemistry and biology are rigorously defined [8].

From an educational and research-methodology standpoint, this area is also valuable because it teaches a hard lesson: interdisciplinary success comes from integration, not accumulation. Putting chemistry, nanotechnology, and biology side by side is not enough. They must be connected by a causal logic. Once that logic is respected, plant-derived bioactive compounds become far more than traditional natural remedies; they become engineerable molecular systems with tunable performance.

Table 3. Translational bottlenecks and practical mitigation strategies.

Bottleneck	Why it matters	Practical response
Raw-material variability	Different harvests and extraction conditions alter phytochemical profile	Standardize botanical source, extraction protocol, and marker compounds
Unclear transformation chemistry	Derivative impurities or unstable intermediates distort efficacy claims	Use full structural characterization and stability testing
Carrier instability during storage	Particle growth or leakage reduces reproducibility	Apply accelerated stability studies and packaging control
Scale-up mismatch	Lab methods may fail under industrial shear, heat, or cost constraints	Design processes with manufacturability in mind from the start
Incomplete safety data	Nano-sized systems may alter biodistribution and immunological behavior	Expand long-term toxicity, biodegradation, and protein-corona studies
Regulatory ambiguity	Hybrid natural-synthetic systems fit poorly into conventional pathways	Develop documentation aligned with quality-by-design and regulatory science

CONCLUSION

Nanostructured technologies offer a powerful route for improving the biological efficacy of plant-derived bioactive compounds, but their true value emerges only when they are integrated with deliberate chemical transformation and mechanism-based formulation design. The evidence synthesized in this article shows that enhancement of efficacy depends on matching each compound’s dominant limitation—poor solubility, instability, low permeability, rapid metabolism, or weak target exposure—with an appropriate combination of molecular modification and nanocarrier architecture. Lipid-based carriers, polymeric nanoparticles, nanoemulsions, micelles, and emerging plant-derived nanostructures each solve different problems; none is universally optimal. Chemical transformation is equally important because it can reshape solubility, stability, carrier compatibility, and release behavior at the molecular level. The most promising future direction is therefore an integrated platform that connects plant raw materials, extraction, transformation chemistry, nanoformulation, biological testing, and scalable manufacturing. To move from promising laboratory results to real biomedical and biotechnological application, the field must strengthen standardization, long-term safety assessment, reproducibility, and regulatory clarity. When these conditions are met, nano-enabled transformation technologies can substantially increase the scientific and practical value of plant-derived bioactive compounds in biological systems.

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SIR Publishers
CENTER FOR INTERNATIONAL SCIENTIFIC PUBLICATIONS
JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |19-03-2026|

THE CHEMICAL ROLE OF BIOGENIC ELEMENTS IN THE HUMAN BODY AND PATHOLOGICAL CONDITIONS ASSOCIATED WITH THEIR DEFICIENCY

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ABSTRACT

This article analyzes the chemical and biological significance of biogenic elements in the human body and explains how their deficiency leads to clinically important pathological conditions. The study was structured around both macroelements and microelements, with special attention to calcium, phosphorus, magnesium, sodium, potassium, iron, iodine, zinc, and selenium. Their participation in enzyme systems, membrane potentials, bone mineralization, oxygen transport, endocrine regulation, antioxidant defense, and cellular signaling was examined from a bioinorganic and clinical perspective. The purpose of the article was to present the physiological roles of these elements within a single conceptual framework and to connect their chemical forms and biological functions with the most common deficiency syndromes observed in medical practice. The analysis showed that biogenic elements are not passive nutritional components but active chemical determinants of metabolism, gene expression, redox balance, and tissue homeostasis. Their deficiency does not usually manifest as an isolated biochemical event; rather, it develops into a multisystem pathological response involving structural, functional, and regulatory disruption. The article also emphasizes that accurate diagnosis requires attention to early biochemical markers before overt clinical disease appears.

Keywords: Biogenic elements, macroelements, microelements, calcium, phosphorus, magnesium, iron, iodine, zinc, selenium, hematopoiesis, hypothyroidism, anemia, hypocalcemia, hypomagnesemia, bioavailability, metabolism

INTRODUCTION

Biogenic elements are chemical elements that form part of living matter and are indispensable for the continuity of vital processes. Some of them are organogenic elements that constitute the fundamental framework of biomolecules, while others are macroelements and microelements that participate in ionic regulation, metalloprotein function, hormone synthesis, membrane stability, and structural organization. When the human body is approached not merely as a collection of organic substances but as a high-order chemically regulated system, the importance of biogenic elements becomes much more evident. Ionic gradients between extracellular and intracellular compartments, enzyme activation, oxidation-reduction reactions, protein synthesis, skeletal mineralization, oxygen transport, and endocrine signaling all depend on them.

From a physiological standpoint, biogenic elements may be divided into several conditional groups. Carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur form the main architecture of organic molecules. Sodium, potassium, calcium, magnesium, and chloride serve as principal macroelements responsible for electrolyte balance, osmolarity, excitability, and structural support. Iron, zinc, iodine, copper, selenium, manganese, and molybdenum are trace elements, yet their low concentration does not imply low importance. On the contrary, they are crucial for metalloenzymes, transcriptional control, hormone biosynthesis, electron transfer, and antioxidant protection. Because of this, trace element deficiency is often detected late, even though its consequences may be severe.

Deficiency of biogenic elements remains a major global health challenge. Iron deficiency is the most common cause of nutritional anemia worldwide. Iodine deficiency disrupts thyroid hormone synthesis and may lead to goiter, hypothyroidism, and impaired neurodevelopment in the fetus and child. Inadequate calcium and vitamin D intake contributes to rickets, osteomalacia, and reduced bone mineral density. Magnesium deficiency increases neuromuscular excitability and can provoke tremor, muscle spasm, and cardiac rhythm disturbances. Deficiency of zinc and selenium weakens immune competence, impairs tissue regeneration, and compromises antioxidant defense. Therefore, the medical significance of biogenic elements extends far beyond nutrition and enters the domain of pathogenesis, prevention, and long-term tissue function.

A persistent problem in clinical practice is that mineral deficiency is often evaluated only as a secondary feature of another syndrome rather than as a primary biochemical disorder. Anemia may be treated as a reduction in hemoglobin concentration without full assessment of iron absorption, ferritin reserves, transferrin saturation, hepcidin regulation, or chronic inflammation. Likewise, goiter is sometimes described only as thyroid enlargement, whereas the underlying mechanism includes reduced synthesis of triiodothyronine and thyroxine, compensatory elevation of thyrotropin, and hyperplastic remodeling of thyroid tissue. Such examples show that the pathological consequences of biogenic element deficiency can only be fully understood when chemistry, cell biology, and clinical medicine are considered together.

The aim of this article is to analyze the chemical role of major biogenic elements in the human organism, to describe their physiological functions at the cellular, tissue, and organ levels, and to explain the principal pathological states associated with their deficiency within the logic of an IMRAD-based scientific article.

MATERIALS AND METHODS

The study was carried out using analytical review and comparative interpretation. Scientific information relevant to the topic was systematized from reliable educational and clinical sources in bioinorganic chemistry, medical biochemistry, nutrition science, physiology, endocrinology, and internal medicine. The analysis focused on the chemical form of each element in the body, its transport and distribution, its participation in structural and regulatory processes, and the characteristic biochemical and clinical consequences of deficiency.

Elements were evaluated according to two principal criteria. The first criterion was physiological role, which included structural, catalytic, transport, and regulatory functions. The second criterion was pathological significance, which included early biochemical markers of deficiency, morphological alterations, clinical manifestations, and systemic complications. On this basis, calcium and phosphorus were grouped as key determinants of mineralized tissue formation; magnesium, sodium, and potassium were interpreted as central modulators of bioelectrical stability; iron was analyzed primarily in relation to oxygen transport and hematopoiesis; iodine was discussed as an essential factor in endocrine control; and zinc and selenium were examined mainly through their enzymatic and antioxidant roles.

The methodological logic of the article was based on three questions for each element: in what chemical form does it operate in the body, through which biological mechanism does its effect become visible, and what pathological picture emerges when deficiency develops. This approach makes it possible to move beyond descriptive enumeration and toward a causal biochemical-clinical interpretation of deficiency states.

Table 1.

Major biogenic elements, their chemical roles, and deficiency-related pathological conditions

Element	**Main chemical form or localization**	**Principal biological role**	**Typical deficiency-related pathology**
Calcium	Hydroxyapatite, ionized Ca^{2+}	Bone mineralization, signaling, coagulation, contraction	Rickets, osteomalacia, tetany, QT prolongation
Phosphorus	Phosphate in ATP, nucleic acids, phospholipids	Energy transfer, membrane structure, buffering	Defective mineralization, weakness, metabolic dysfunction
Magnesium	Mg-ATP complex, intracellular Mg^{2+}	Enzyme cofactor, membrane stabilization, neuromuscular regulation	Cramps, tremor, arrhythmia, refractory hypokalemia
Sodium	Extracellular Na^+	Osmotic balance, nerve conduction, fluid distribution	Hyponatremia with confusion, seizures, cerebral edema
Potassium	Intracellular K^+	Membrane potential, muscle function, cardiac rhythm	Weakness, ileus, arrhythmias
Iron	Hemoglobin, ferritin, cytochromes	Oxygen transport, redox reactions, hematopoiesis	Microcytic hypochromic anemia, fatigue, cognitive decline
Iodine	Thyroid hormones T_3 and T_4	Endocrine regulation, growth, neurodevelopment	Goiter, hypothyroidism, developmental impairment
Zinc	Metalloenzymes, zinc-finger proteins	Immune function, repair, transcriptional regulation	Dermatitis, growth delay, recurrent infections
Selenium	Selenoproteins, glutathione peroxidase	Antioxidant defense, redox control, thyroid support	Oxidative injury, cardiomyopathy, immune weakness

RESULTS

The results of the analysis show that the role of biogenic elements in the human body becomes visible through three major functional directions: structural support, metabolic catalysis, and physiological regulation. Calcium and phosphorus represent the clearest example of structural and signaling duality. Calcium is the most abundant mineral in the body, and most of it is stored in bones and teeth in the form of hydroxyapatite crystals. However, its role is not limited to the skeleton. In the cytosol calcium acts as a second messenger that transduces hormonal and neurotransmitter signals, initiates muscle contraction, contributes to blood coagulation, and modulates membrane excitability. Phosphorus participates in adenosine triphosphate, phosphocreatine, nucleic acids, and membrane phospholipids; it is therefore indispensable for energy metabolism and cellular architecture. Long-standing deficiency of calcium, phosphorus, or their functional partners leads to impaired mineralization, which manifests as rickets in children and osteomalacia or osteopenia in adults.

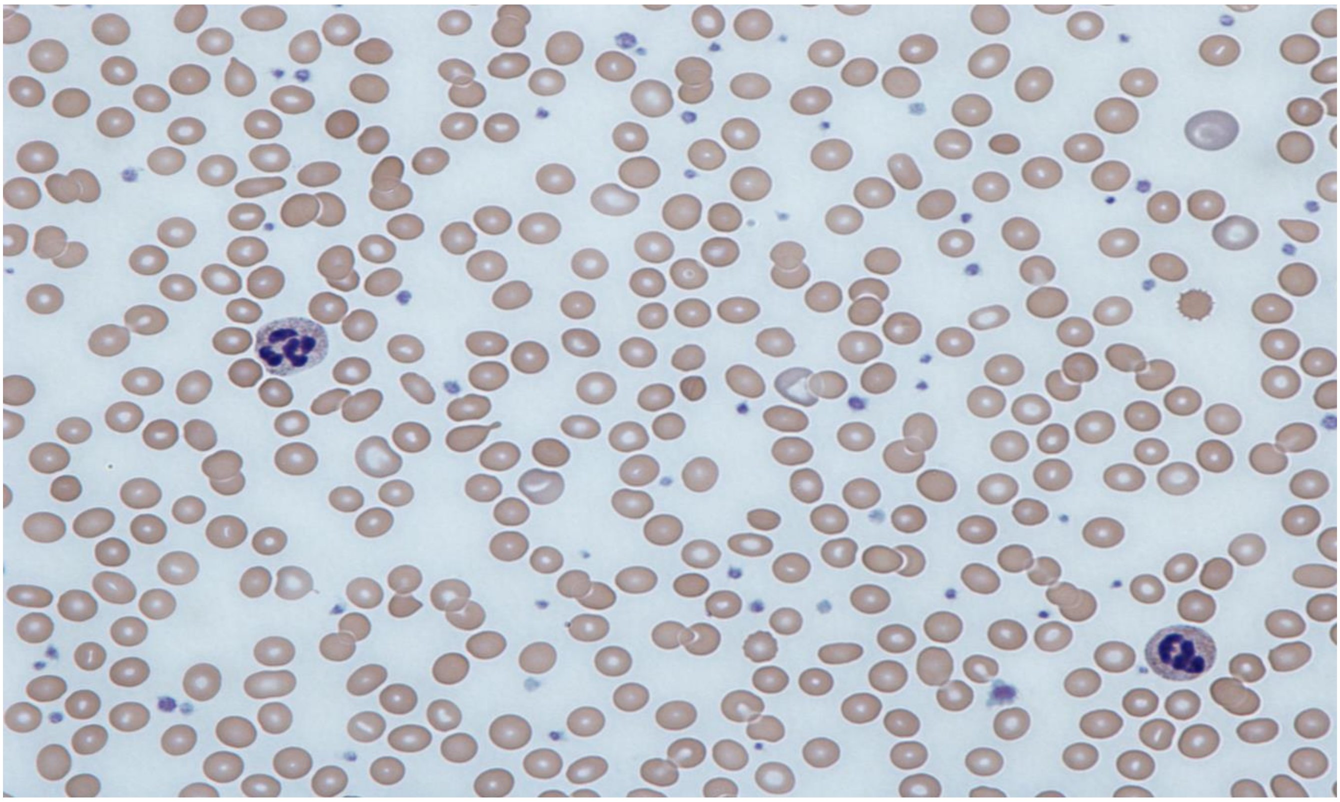
Magnesium occupies a special place in biochemical energetics. Within the cell, ATP is rarely active as a free molecule and usually functions as the Mg-ATP complex. This means that magnesium is necessary for a large number of phosphorylation reactions and for the normal activity of ATP-dependent enzymes. It also modulates calcium transport, stabilizes excitable membranes, and exerts a physiological restraining effect on neuromuscular transmission. For this reason, hypomagnesemia may present with tremor, increased reflexes, muscle cramps, eyelid twitching, weakness, and ventricular arrhythmias. In practice, magnesium deficiency is frequently accompanied by hypokalemia or hypocalcemia because the homeostasis of these ions is interdependent. The analysis therefore confirms that element deficiency often develops as a network disorder rather than a single isolated abnormality.

Sodium and potassium are the central determinants of cellular bioelectric life. Sodium predominates in extracellular fluid, whereas potassium is concentrated intracellularly. The sodium-potassium ATPase preserves this asymmetry and thereby maintains resting membrane potential, nerve impulse conduction, osmotic stability, and muscle excitability. When potassium becomes deficient, the membrane becomes abnormally hyperpolarized, skeletal muscle weakness appears, gastrointestinal motility decreases, and dangerous cardiac rhythm disturbances may arise. Sodium deficiency, depending on acuity and severity, leads to headache, nausea, confusion, seizures, and cerebral edema. Although sodium and potassium disorders are not always caused by inadequate dietary intake alone, their role as biogenic electrolytes remains fundamental for understanding neuromuscular and cardiovascular physiology.

Iron differs qualitatively from many other essential elements because it possesses variable valence and therefore participates in oxygen binding, electron transport, and redox catalysis. Iron is a core component of hemoglobin, myoglobin, cytochromes, catalase, and multiple iron-sulfur proteins. Its deficiency first reduces body iron stores, then impairs erythropoiesis, and finally produces microcytic hypochromic anemia. At the tissue level, iron deficiency causes cellular hypoxia, fatigue, reduced exercise tolerance, cognitive decline, epithelial changes, hair loss, brittle nails, and in children delayed psychomotor development. The pathological picture is especially important in women of reproductive age, infants, adolescents, and patients with chronic inflammatory or gastrointestinal disorders.

Iodine has an endocrine role of exceptional importance because iodine atoms are indispensable for the biosynthesis of thyroxine and triiodothyronine. These hormones regulate basal metabolic rate, thermogenesis, growth, brain development, and the metabolic activity of almost every tissue. In conditions of iodine deficiency, thyroid hormone production falls and thyrotropin rises as a compensatory response. Persistent stimulation leads to thyroid hyperplasia and enlargement, producing goiter. In severe or prolonged deficiency, hypothyroidism develops, accompanied by fatigue, cold intolerance, bradycardia, constipation, slowed cognition, dry skin, and in children growth and neurodevelopmental impairment. The analysis shows that iodine deficiency is not simply a local glandular problem but a systemic regulatory disorder with pronounced developmental consequences.

Zinc and selenium, although required in trace quantities, display major biological efficiency. Zinc participates in many metalloenzymes, nucleic acid metabolism, transcription factors, and so-called zinc-finger proteins. It is essential for epithelial integrity, wound healing, reproductive function, immune competence, and normal growth. Zinc deficiency may present with dermatitis, delayed healing, growth retardation, taste disturbance, alopecia, and recurrent infections. Selenium, by contrast, is incorporated into selenoproteins such as glutathione peroxidase and thioredoxin reductase, both of which are central to antioxidant defense and redox signaling. Selenium deficiency weakens cellular protection against oxidative injury and has been linked with cardiomyopathy, thyroid dysfunction, impaired immune responses, and reduced resilience under inflammatory stress. These findings demonstrate that trace elements cannot be regarded as minor simply because they are present in small amounts.



Figure

1. Peripheral blood smear in iron deficiency anemia showing hypochromia and anisocytosis of erythrocytes

Figure 2.

Clinical appearance of goiter associated with iodine deficiency

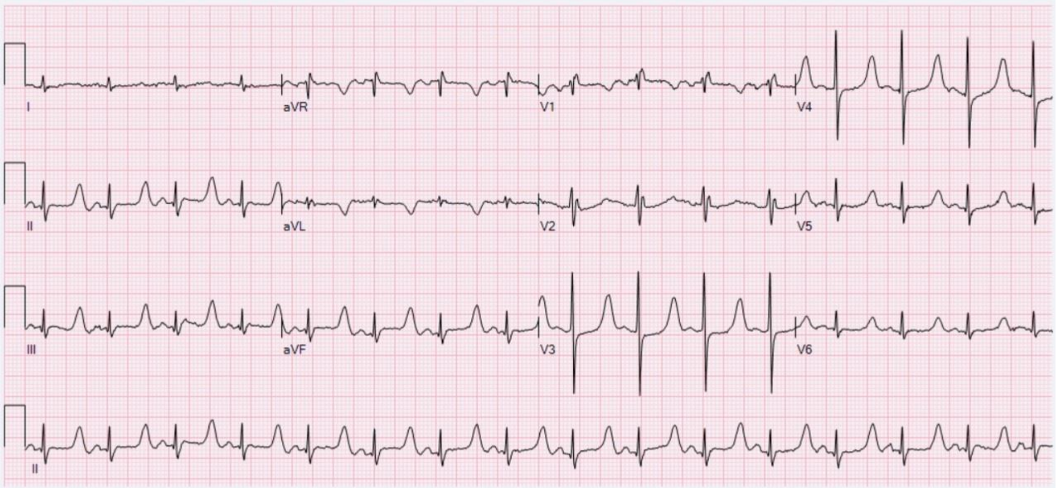


Figure 3.

Electrocardiographic changes in hypocalcemia with ST-segment prolongation and QT interval extension

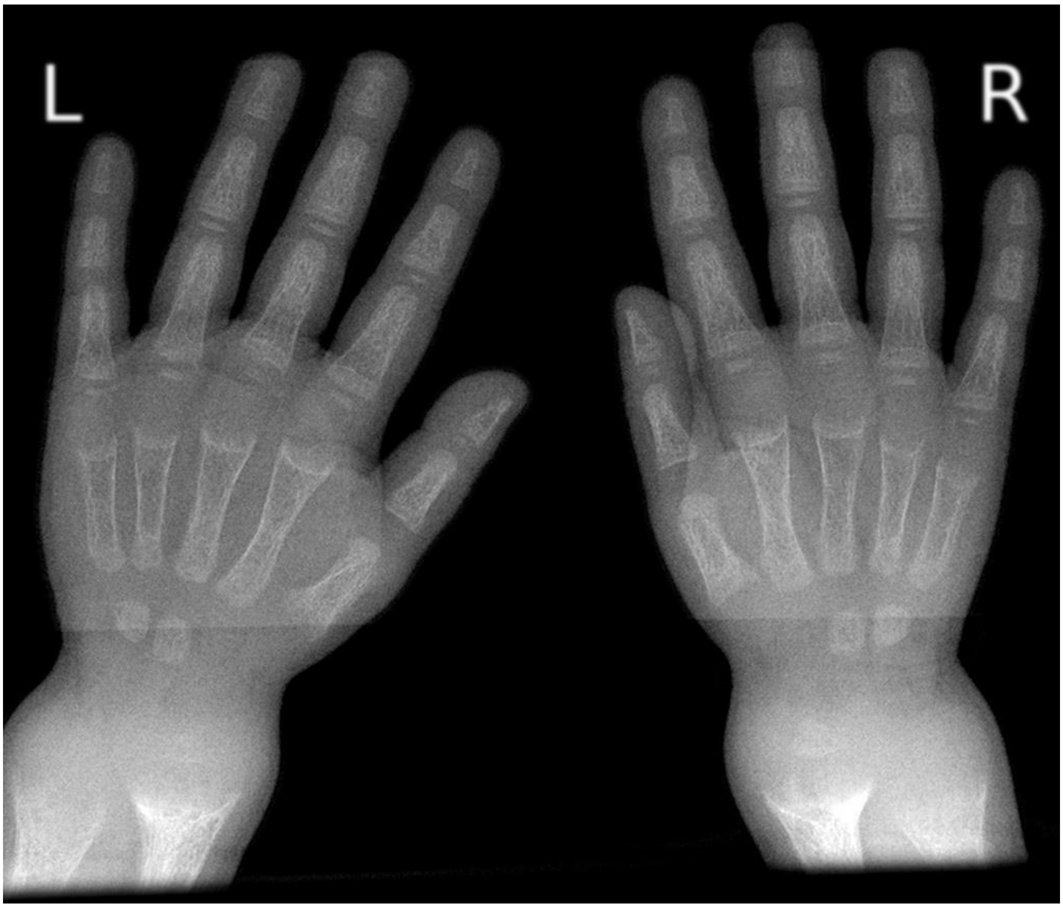


Figure 4.

Radiographic wrist changes in rickets associated with calcium and vitamin D deficiency

DISCUSSION

The findings of this review confirm that deficiency of biogenic elements is rarely confined to a single organ system. The reason lies in the fact that these elements operate within multilayered chemical networks. Calcium deficiency, for example, affects not only bone mineralization but also membrane signaling, coagulation, and neuromuscular excitability. Magnesium deficiency not only compromises ATP-dependent reactions but may also disturb potassium retention and parathyroid hormone regulation, thereby aggravating hypokalemia and hypocalcemia. Iron deficiency primarily presents as anemia, yet its consequences extend to mitochondrial energy production, immune response, epithelial health, and neurocognitive performance. This multidimensionality explains why clinical manifestations are often heterogeneous and why isolated symptom-based treatment is frequently inadequate.

Interactions among biogenic elements are equally important. The ratio of calcium to phosphorus influences hydroxyapatite formation and skeletal stability. Excessive or imbalanced phosphate exposure may aggravate mineral dysregulation when calcium intake is insufficient. Magnesium contributes to the secretion and action of parathyroid hormone and indirectly modulates calcium balance. Iron absorption is improved by ascorbic acid and inhibited by phytates, polyphenols, and some gastrointestinal conditions. Iodine metabolism is affected by environmental exposure, thyroid demand, and population-level salt iodization practices. Zinc and selenium participate in overlapping immune and antioxidant pathways, so deficiency of one may amplify the biological effects of deficiency of the other. For this reason, biogenic element disorders should not be interpreted in isolation.

Another major implication concerns early diagnosis. Clinical signs often appear only after biochemical reserves are already depleted. Ferritin may fall well before overt iron-deficiency anemia emerges. In iodine deficiency, subtle reductions in thyroid hormone economy may precede visible goiter. Magnesium deficiency can remain hidden because serum values do not always reflect intracellular depletion. Calcium disorders may initially manifest through electrophysiological or neuromuscular signs before structural consequences become obvious. Therefore, preventive laboratory assessment, risk stratification, and dietary history are essential, especially in children, pregnant women, older adults, and patients with chronic gastrointestinal, renal, endocrine, or inflammatory diseases.

The practical conclusion of this analysis is that deficiency of biogenic elements cannot be corrected effectively by unsystematic supplementation alone. Rational intervention must include dietary improvement, fortification strategies, evaluation of absorption disorders, treatment of underlying disease, and attention to element-element interactions. From a public health perspective, iodized salt, iron supplementation in high-risk groups, correction of pediatric calcium and vitamin D deficiency, and adequate intake of magnesium, zinc, and selenium remain important preventive measures. From a clinical perspective, the chemistry of each element should guide both diagnosis and therapy. A patient does not suffer from a vague lack of minerals; the patient suffers from the failure of specific chemical systems that support life.

CONCLUSION

Biogenic elements in the human body are not merely structural additives but active determinants of metabolism, membrane transport, hormone biosynthesis, antioxidant defense, bioelectrical stability, and tissue regeneration. Their importance becomes especially clear when deficiency develops and transforms normal physiology into recognizable pathology.

Calcium and phosphorus support skeletal mineralization while also contributing to signaling and energy transfer. Magnesium is indispensable for enzymatic activity and neuromuscular balance. Sodium and potassium preserve membrane potential and excitability. Iron enables oxygen transport and redox metabolism. Iodine ensures thyroid hormone synthesis. Zinc and selenium support catalytic, immune, reparative, and antioxidant systems.

Deficiency of these elements commonly manifests as multisystem disorders such as microcytic anemia, goiter, hypothyroidism, rickets, osteomalacia, tetany, arrhythmias, dermatitis, impaired growth, and immune dysfunction. For that reason, diagnosis should be early and chemically informed, and prevention should combine nutrition, laboratory screening, and targeted public health strategies.

Further research should deepen the study of individual bioavailability, intestinal microbiota interactions, genetic polymorphisms, and combined mineral deficiencies, because these factors may determine why deficiency presents differently among patients exposed to similar nutritional conditions.

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SIR Publishers
CENTER FOR INTERNATIONAL
SCIENTIFIC PUBLICATIONS
JOURNAL OF CHEMISTRY
ISSN(Online): 2984-8075
Volume-9, Issue-01, Published |23-03-2026|

USING VARIOUS ACCELERATOR SYSTEMS, IT IS POSSIBLE TO INFLUENCE THE PROPERTIES OF

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ANNOTATION

An increase in the proportion of intermolecular and a decrease in the proportion of intra-molecular bonds. The main ingredients of elastomeric compositions are fillers, their purpose is to change the volume and properties of the composition and quality indicators in the right direction. Achieving this goal is primarily related to the nature of the combination of elastomer and filler, as well as the nature of their interaction.

Keywords: intermolecular, ingredients, elastomeric composition, elastomer, temperature, chemistry, oils, acids, deformation.

Rubber products used in mechanical engineering are made from rubber compounds consisting of various components, which the main ones include:

elastomers-natural and synthetic, such as isoprene, styrene butadiene, chloroprene, nitrile rubbers, widely used in the manufacture of tires and rubber products;

fillers-mineral and organic such as carbon black (soot), chalk, kaolin and other materials that increase the strength and wear resistance of rubber;

plasticizers-oils and other substances that improve the ductility and processing of rubber compounds;

Vulcanizing agents-sulfur as a vulcanizing agent, accelerators to eradicate the vulcanization process, metal oxides to activate the vulcanization process;

stabilizers and antioxidants are used to protect the product from external aggressive processes.

The production process of rubber compounds consists in the mechanical mixing of rubbers and ingredients on special equipment, such as mixing rollers or rubber mixers of a closed type.

In addition, materials such as polyethylene terephthalate (PET) are used to reinforce rubber products, which enhances the mechanical and physical properties of products. Thus, rubber products play a key role in various industries, the combination of these components provides the necessary properties of rubber products for their effective use in mechanical engineering, railway and aviation equipment.

Very high technical requirements are imposed on rubber and rubber products. Serial rubbers based on natural and synthetic (SKI-3, SKD, SCS) rubbers do not meet these requirements. The development of technology has necessitated the creation of special rubbers with high oil, frost and fire resistance, indifference to various chemical agents, mechanical strength and other properties, as well as the manufacture of rubber products resistant to sudden changes in temperature and humidity, capable of operating in an environment with a high ozone content. Special rubber products are rubber products designed to perform specific functions in various industries. Their technical characteristics depend on the purpose, operating conditions and materials used.

Due to further technological progress, the requirements for the properties and quality of special rubbers are increasing, and in some cases it becomes necessary to give special properties to rubbers. Obtaining special rubber products includes several key stages of technology, depending on the type of product (seals, belts, hoses, gaskets, etc.).

Special rubber products (SRTI) are products made of rubber or rubber–woven materials and designed to work under special operating conditions. Such products include, for example, reinforced hoses, sealing elements for aggressive media, vibration-proofing and shock-absorbing components, as well as products operating at extreme temperatures or under high pressure.

The basis of rubber products are elastomers, which can be natural or synthetic (butyl rubber, silicone rubbers, fluoro rubbers, etc.), The introduction of fillers (soot, silica), plasticizers, vulcanizing agents (sulfur, peroxides) allows you to regulate the mechanical and operational properties.

To give rubber products used in modern engineering, railway and aviation equipment the required properties, rubbers are mixed with organic or inorganic, bulk or liquid substances and then subjected to vulcanization. Most of the ingredients change the properties of not only vulcanizates, but also rubber compounds and thus affect their behavior in production processes.

Vulcanizing agents are chemically active compounds involved in the formation of spatial structure during the vulcanization of rubber compounds. During the formation of the spatial structure, with an increase in the degree of crosslinking, there is a decrease in the number-average (Ms) segments of polymer chains and, accordingly, an increase in the number of cross-links per unit volume of the vulcanizer (□).

With a change in the degree of cross-linking during vulcanization, a gradual change in the properties of the vulcanizer occurs in rubber compounds. The equilibrium modulus increases with increasing density of the vulcanization mesh and, in accordance with the molecular kinetic theory of elasticity, increases in direct proportion to the number of cross-links or inversely proportional to the average molecular weight of the chain segments between the nodes of the spatial vulcanizate mesh.

The change in hardness and strength characteristics of vulcanizates depends on many factors. Thus, during the vulcanization of sulfur rubbers, depending on the content of the attached sulfur, and hence on the density of the vulcanization mesh, first up to the content of bound sulfur about

5 wt.h. there is an increase in the tensile strength of vulcanizates. Such vulcanizate has the properties of soft rubber. With a further increase in the content of bound sulfur to 10 wt.h. the strength of vulcanizates decreases, the material becomes rigid, leathery. If the content of bound sulfur is further increased, the strength of the vulcanizate increases again, and it will turn into solid ebonite. This is because when a certain degree of crosslinking is achieved, the distance between some nodes becomes too small as a result of uneven crosslinking, which makes it difficult to orient the molecular chains when stretched. This leads to local overvoltages, therefore, to the rupture of circuits in these places. A further increase in bond strength is associated with the transition from highly elastic to elastic deformation, and the strength in this case will be due to purely chemical bonds .

As the density of the vulcanization mesh increases, the relative and residual elongations decrease to very small values typical of brittle materials. At the same time, elasticity varies according to a complex dependence, the maximum elastic properties are manifested with such a density of the vulcanization mesh, at which maximum strength is observed for soft rubbers. In addition, swelling in solvents decreases in proportion to an increase in the degree of crosslinking.

To obtain rubbers with a given set of properties, it is necessary to ensure a certain degree of cross-linking of elastomers by introducing a certain amount of vulcanizing substances into the composition. The number of cross-links formed will depend on the nature of the rubber, the nature and content of the vulcanizing agent, and the conditions of vulcanization.

Some accelerators are also vulcanizing substances. For example, tiaras and poly sulfide accelerators at the vulcanization temperature can vulcanize some rubbers without the use of elemental sulfur. The activity of most accelerators increases with the introduction of metal oxides, stearic acid, etc. Vulcanization accelerators for one type of rubber may completely lose the properties of accelerators and play a different role in compositions based on another rubber. For example, dibenzthiazolyl disulfide, being an accelerator of vulcanization of natural and styrene butadiene rubbers, serves as a retarder under vulcanization and a plasticizer for narite.

The use of organic accelerators has made the most significant changes in the process of rubber vulcanization. They significantly improve the technical properties of vulcanizates, increase the resistance of rubber products to aging, create the possibility of obtaining homogeneous massive products, shorten the duration of vulcanization, as a result of which the number of equipment and energy consumption are reduced several times, and labor productivity increases. Many accelerators are mutually activated during vulcanization. Using various accelerator systems, it is possible to influence the properties of vulcanizates, change the “rubber-stretching” curve, increase stress at a certain elongation and strength properties even in the absence of reinforcing fillers. Organic accelerators exhibit an active effect during vulcanization in the presence of certain metal oxides and hydroxides. Metal oxides have the most effective effect in the presence of fatty acids such as stearins, palmitic acid, oleic acid, etc.

The nature of the activators depends on the type of rubber, the accelerators used, the fillers and the vulcanization temperature. The effect of activators on the structure of vulcanizates and, accordingly, on the physical, mechanical and operational properties of vulcanizates is diverse. In the presence of zinc oxide, zinc salts of accelerators and zinc sulfide are always formed during vulcanization of the rubber compound. The resulting vulcanizates are characterized by higher physical and mechanical strength, tear resistance and dynamic endurance, while the rate of sulfur addition increases slightly. It has been found that in the presence of activators, the concentration of cross-links increases with the same amount of bound sulfur. This indicates an increase in the proportion of intermolecular bonds and a decrease in the proportion of intra - molecular bonds . The main ingredients of elastomeric compositions are fillers, their purpose is to change the volume and properties of the composition and quality indicators in the right direction. Achieving this goal is primarily related to the nature of the combination of elastomer and filler, as well as the nature of their interaction.

It has been established that the limitation of the mobility of elastomer chains as a result of its interaction with the filler is more noticeable the more the surface of the latter is developed. The reinforcing ability of the filler is significantly influenced by its properties such as dispersion, agglomeration and the chemical nature of the surface. With an increase in the dispersion of the filler and the wettability between its surface and the elastomer macromolecules, the overall limiting effect of the filler on the reinforcement of the elastomeric composition increases. The type of filler and its content in composite elastomeric materials are selected taking into account the overall effect of the filler on its physical properties.

The choice of filler is determined primarily by the size of its particles and their size distribution, as well as the shape of the particles and the nature of their packaging. The division of particles into classes is quite arbitrary and is based on the difference in the surface area of the particles. This classification takes into account two main characteristics of dispersed fillers - particle size and surface area, which can be realistically measured and therefore serve as the basis for the systematization of fillers for their intended purpose. The size of the filler particles is crucial in reinforcement, provided that other factors affecting reinforcement, such as the surface tension at the rubber-filler interface, the shape of the filler particles, and the distribution of filler particles in the composition, remain constant. The particle shapes of most fillers vary enormously and cannot be strictly characterized. Therefore, only particle sizes and their surface area can serve as a basis for classifying fillers and assessing their effect on the properties of polymer-filler systems.

Fillers of polymer mixtures are usually rather fine powders, which allows for a fairly uniform distribution of filler particles in the polymer. At the same time, the full use of the filler surface is possible only if each particle of the filler is surrounded by a rubber film. The dispersion of the filler depends not only on its tendency to agglomeration and flocculation, but also on the surface activity (lubricity) at the polymer-filler interface. The energy used in the dispersion of soot is spent mainly on overcoming the interaction between particles or primary aggregates. The interaction between particles or primary aggregates is greater in dispersed carbon black, because with a decrease in particle size, the number of active sites and oxygen-containing groups located on their surface increases.

Despite the increased energy consumption, non-dispersed filler particles are no longer found in mixtures containing dispersed fillers. At the same time, in mixtures where the filler has larger particles, a smaller number of non-dispersed particles are found. This is due to the fact that highly dispersed carbon black, having significant free energy, is capable of forming strong agglomerates. In addition, with an increase in the dispersion of soot, its specific surface area increases, which must be moistened with rubber.

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