Workshop on Challenges and Innovations in Nanotechnology
18-19 December, Damascus- Syria

Application of nanotechnology in the field of agriculture (nano-pesticides and nano-fertilizers)

Prof. Seid Mahdi Jafari

Dec, 2019
Damascus, Syria

چشم دل باز کن که جان بینی — آن‌چه نادیدنی‌ست آن بینی
دل هر ذره را که بشکافی — آفتابش در میان بینی
هاتف اصفهانی

A brief biography

- PhD from the University of Queensland (Australia), in 2007.
- Working on nanoencapsulation of food bioactives for the past 15 years.
- A full professor, and academic member of GUASNR (Iran).
- Publishing >200 papers (h-index= 50) in top-ranked international journals
- Editing 36 books along with 37 book chapters with Elsevier, Springer, and Taylor.
- One of the top 1% world scientists in the field of Biological Sciences (Thomson Reuters, Essential Scientific Indicators); Nov, 2015.
- One of the top national researchers (Iranian Ministry of Science, Research, and Technology); Nov, 2017.
- One of the world's highly cited researchers (Clarivate Analytics, Web of Science); Nov 2018 and 2019.
- Top reviewer in the field of agricultural and biological sciences (Publons, Web of Science); Sep, 2017-2019.

OUTLINE

1. Introduction

2. Appropriate Nanocarriers and Nanodelivery Systems for Agrochemicals

3. Preparation of Different Nanoencapsulated Agrochemicals

4. Application of Nanoencapsulated Agrochemicals in Practice

5. Future Prospects of Nanoencapsulation in Agriculture

INTRODUCTION

- Agrochemicals play an important role in agricultural production.
- The application of nanotechnology in pesticide delivery is relatively new and in the early stages of development.
- The focus of ongoing research was on the development of a nanoencapsulated pesticide formulation that has slow releasing properties with enhanced solubility, permeability, and stability.
- Nanoencapsulated pesticide formulation is able to reduce the dosage of pesticides and human exposure to them, which is environmentally friendly for crop protection.

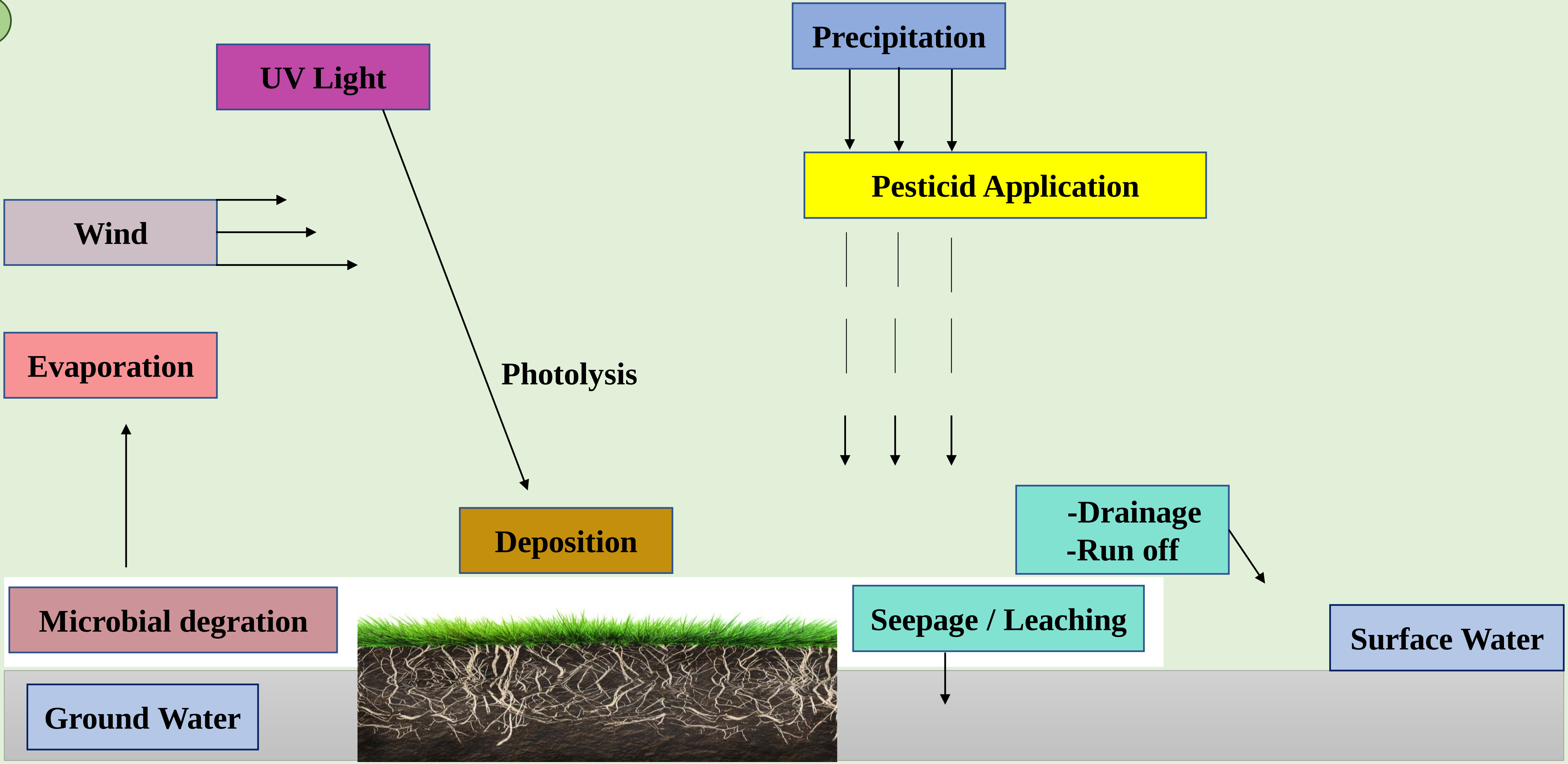

Fig 1. Pathways of pesticide losses and degradation

Appropriate Nanocarriers and Nanodelivery Systems for Agrochemicals

Nanoencapsulation Materials For Agrochemicals Delivery

- Lipid Based
- Polymer Based
- Porous Based
- Other Materials
- Clay Based

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Nanoencapsulation in the Food Industry

Biopolymer Nanostructures for Food Encapsulation Purposes

Volume 1

Edited by

Seid Mahdi Jafari, Gorgan University of Agricultural Sciences and Natural resources, IRAN.

Biopolymer Nanostructures for Food Encapsulation Purposes, a volume in the *Nanoencapsulation in the Food Industry* series, guides readers on how to fabricate nanostructures/nanocarriers from different proteins and polysaccharides and apply them for food encapsulation purposes.

One of the main technologies for preparing nanoencapsulated bioactive ingredients and nutraceuticals is application of biopolymeric nanocarriers. This book covers recent and applied research in all disciplines of bioactive and nutraceutical delivery systems. All chapters emphasize original results relating to experimental, theoretical, formulation, and/or applications of nanostructured biopolymers.

Key Features

- Provides updated formulation and preparation of biopolymeric nanocarriers from proteins and polysaccharides
- Discloses knowledge and potential of biopolymer nanostructures for encapsulation
- Brings the novel applications of biopolymer nanostructures in developing bioactive delivery systems

About the Editor

Prof. Seid Mahdi Jafari received his PhD from the University of Queensland (Australia), in 2006. He has been working on nanoencapsulation of food bioactives for the past 15 years. Now, as a full Professor, he is an academic member of GUASNR (Iran). He has published more than 150 papers in top-ranked International Journals (h-index=35 in Scopus) and 30 book chapters along with editing 11 books with Elsevier. In November 2015, he was awarded as one of the top 1% world scientists by Thomson Reuters (Essential Scientific Indicators) in the field of Biological Sciences. Also in December 2017, he was selected as one of the top national researchers by the Iranian Ministry of Science, Research, and Technology. Recently in November 2018, he was awarded as one of the world highly cited researchers by Clarivate Analytics (Web of Science).

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Jafari

Biopolymer Nanostructures for Food Encapsulation Purposes

Volume 1

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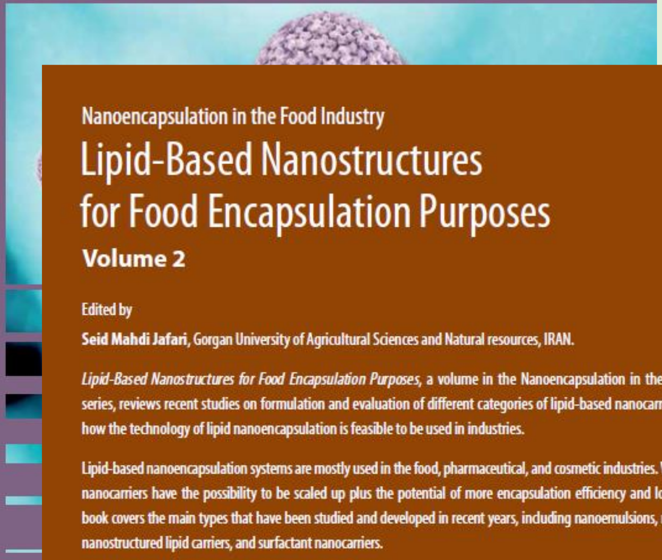
Nanoencapsulation in the Food Industry



Nanoencapsulation in the Food Industry

Lipid-Based Nanostructures for Food Encapsulation Purposes

Volume 2

Edited by

Seid Mahdi Jafari, Gorgan University of Agricultural Sciences and Natural resources, IRAN.

Lipid-Based Nanostructures for Food Encapsulation Purposes, a volume in the Nanoencapsulation in the Food Industry series, reviews recent studies on formulation and evaluation of different categories of lipid-based nanocarriers, discussing how the technology of lipid nanoencapsulation is feasible to be used in industries.

Lipid-based nanoencapsulation systems are mostly used in the food, pharmaceutical, and cosmetic industries. Water-insoluble nanocarriers have the possibility to be scaled up plus the potential of more encapsulation efficiency and low toxicity. This book covers the main types that have been studied and developed in recent years, including nanoemulsions, nanoliposomes, nanostructured lipid carriers, and surfactant nanocarriers.

Key Features

- Brings recent studies on formulation and evaluation of different categories of lipid-based nanocarriers
- Discusses how technology of lipid nanoencapsulation can be used in industries
- Summarizes the practical application of nanostructures from lipid formulations such as nanoemulsions, nanoliposomes, nanostructured lipid carriers and surfactant nanocarriers

About the Editor

Prof. Seid Mahdi Jafari received his PhD from the University of Queensland (Australia), in 2006. He has been working on nanoencapsulation of food bioactives for the past 15 years. Now, as a full Professor, he is an academic member of GUASNR (Iran). He has published more than 150 papers in top-ranked International Journals (h-index=35 in Scopus) and 30 book chapters along with editing 11 books with Elsevier. In November 2015, he was awarded as one of the top 1% world scientists by Thomson Reuters (Essential Scientific Indicators) in the field of Biological Sciences. Also in December 2017, he was selected as one of the top national researchers by the Iranian Ministry of Science, Research, and Technology. Recently in November 2018, he was awarded as one of the world highly cited researchers by Clarivate Analytics (Web of Science).

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Lipid-Based Nanostructures for Food Encapsulation Purposes

Volume 2

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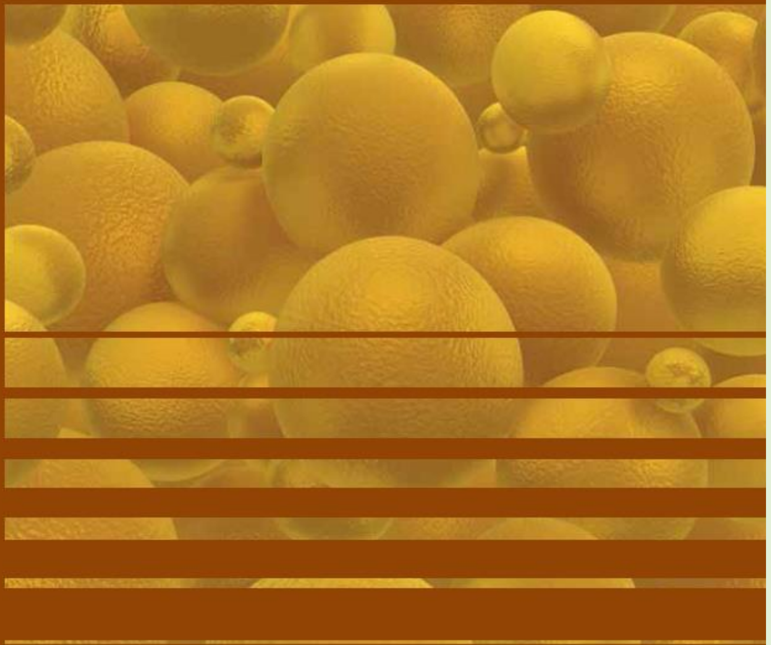
Nanoencapsulation in the Food Industry



Volume 2

Lipid-Based Nanostructures for Food Encapsulation Purposes

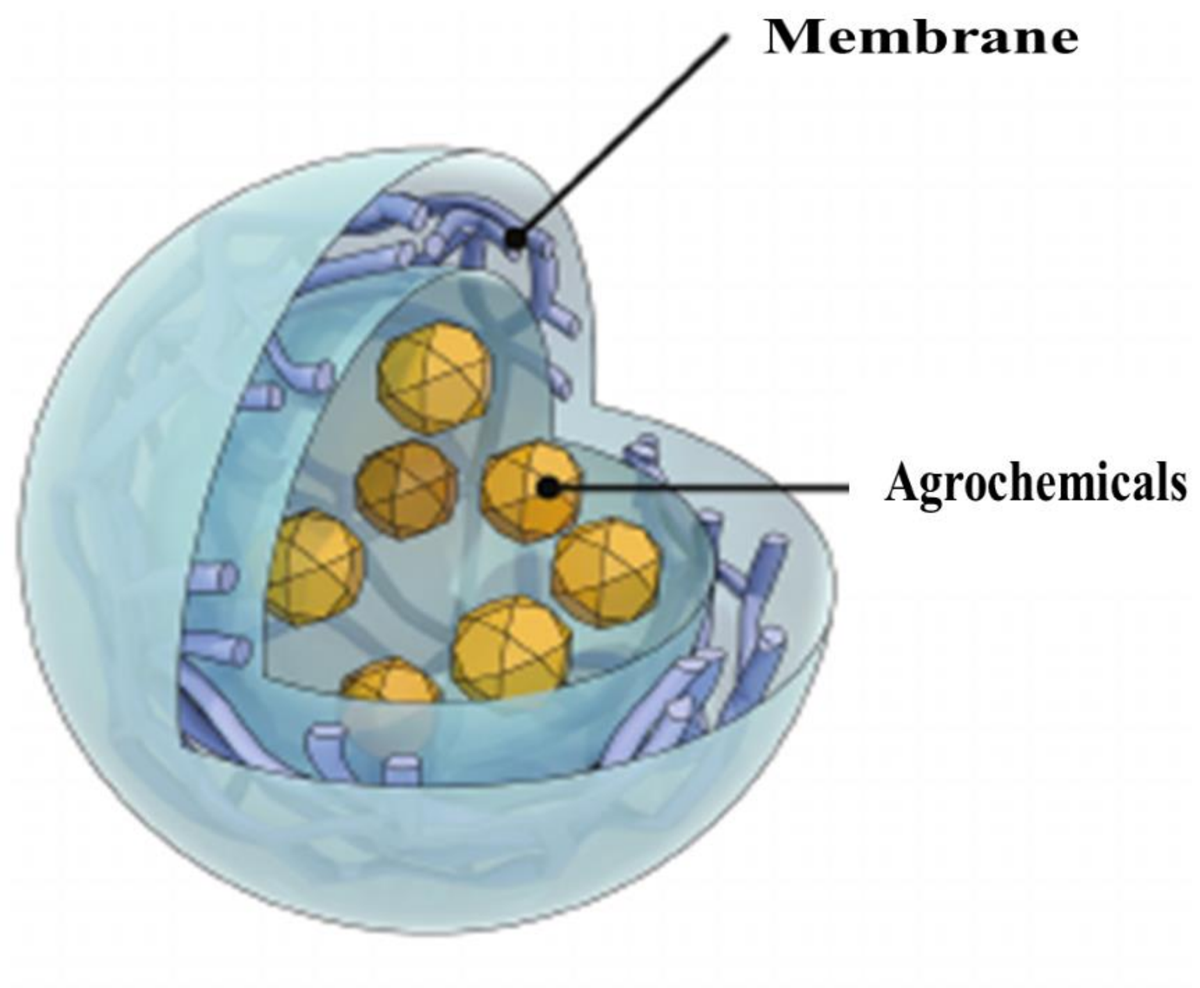
Edited by

Seid Mahdi Jafari

Polymer-Based

- Nanocapsules
- Nanospheres
- Micelles
- Nanogels

Nanocapsules

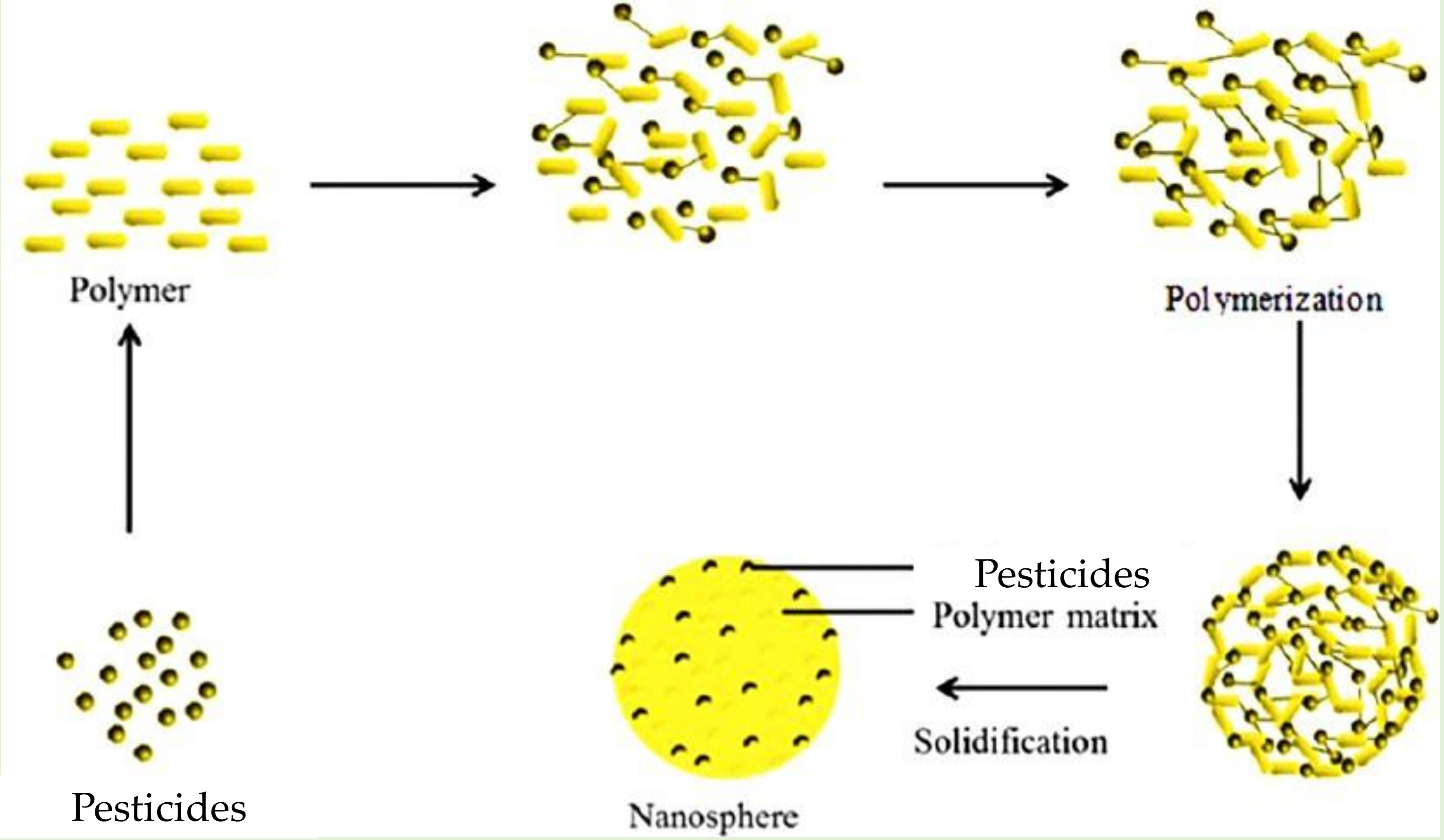


Vesicular systems that are made up:

- A polymeric membrane
- The active compounds

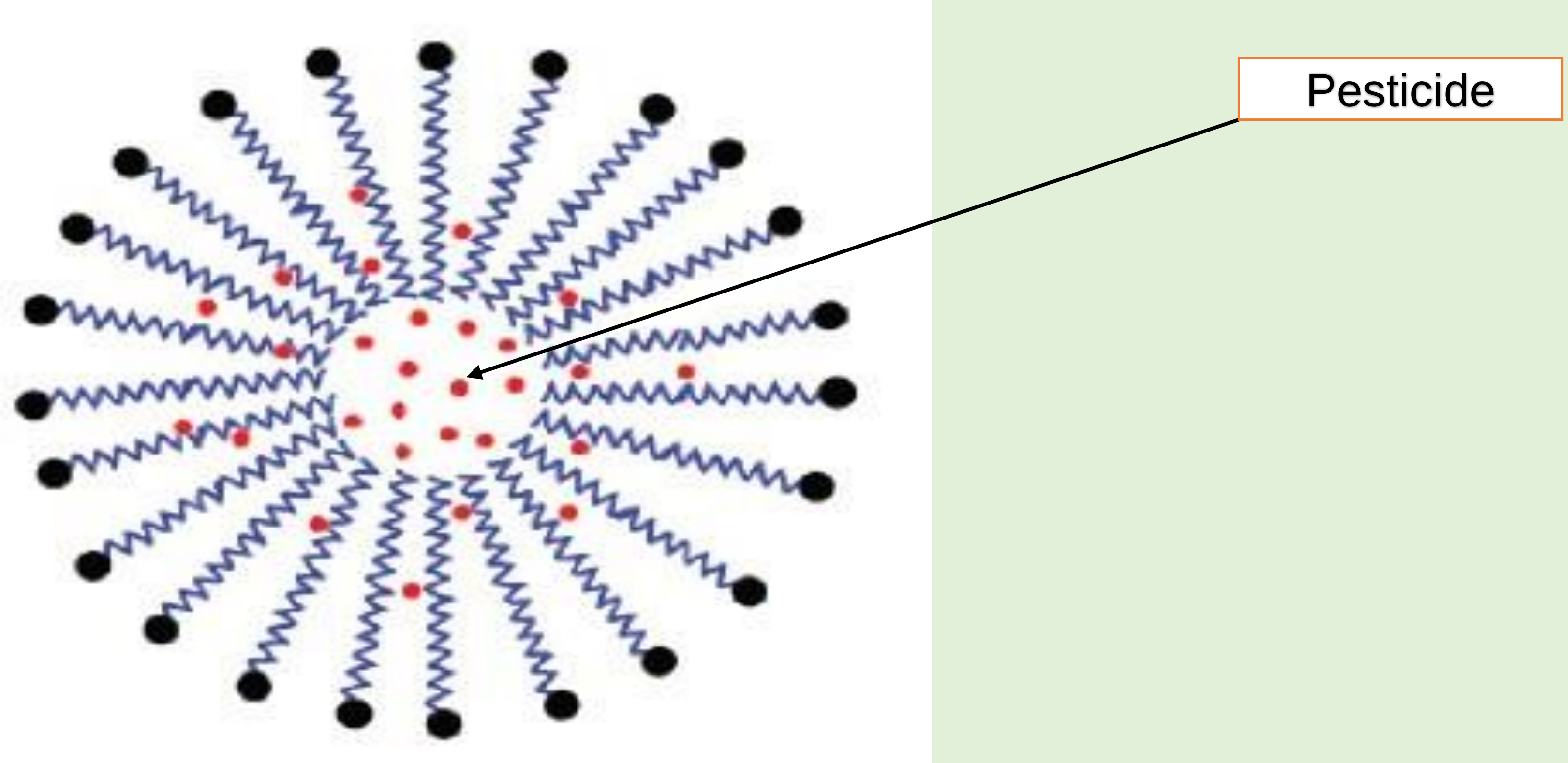
- Constitute the active nanocarrier system
- The active compounds are uniformly distributed and embedded into the polymeric matrix

Nanospheres

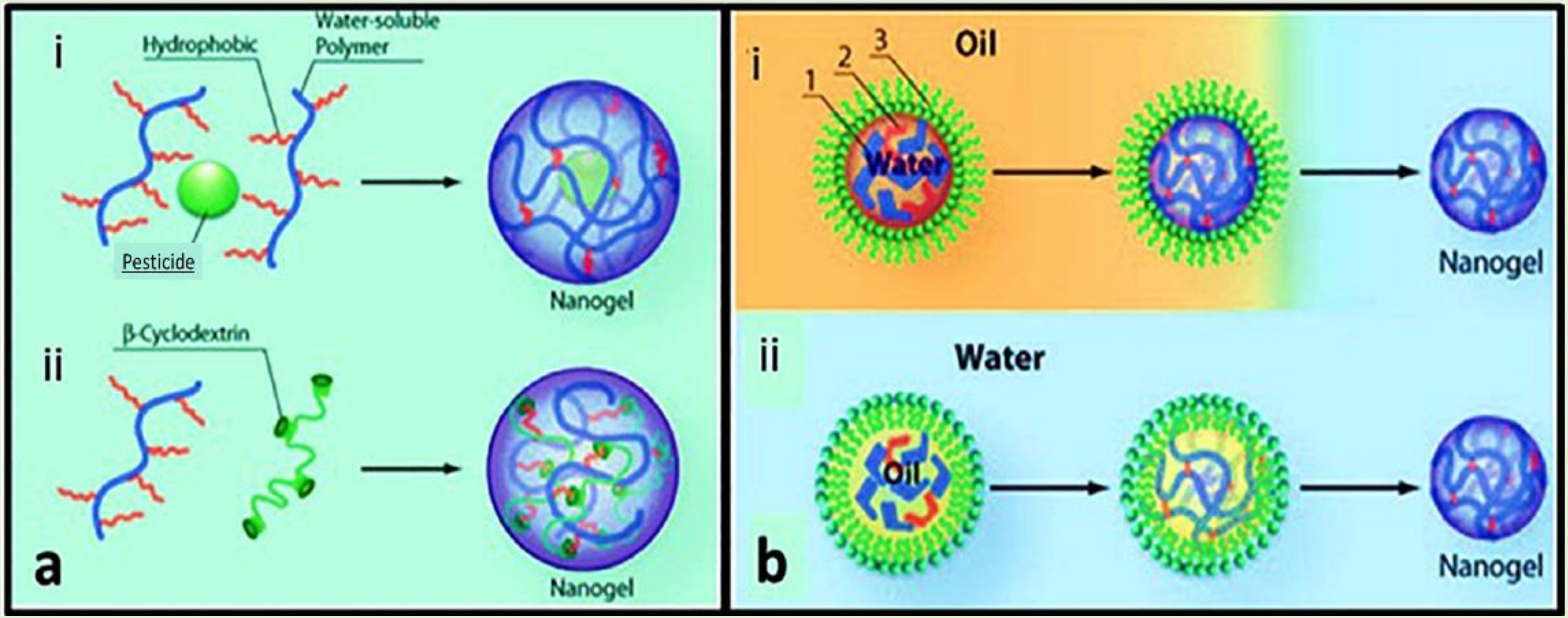


- Micelles are ideal bioactive nanocarriers for encapsulating pesticides, especially for water-insoluble agents.

Micelles



Nanogels



(i) Physical assembly of interactive polymers
(ii) Polymerization of monomers in a homogeneous phase or in a micro- or nanoscale heterogeneous environment
(iii) Cross-linking of preformed polymers
(iv) Template-assisted nanofabrication of nanogel particles

Lipid-Based

Liposomes

SLNs

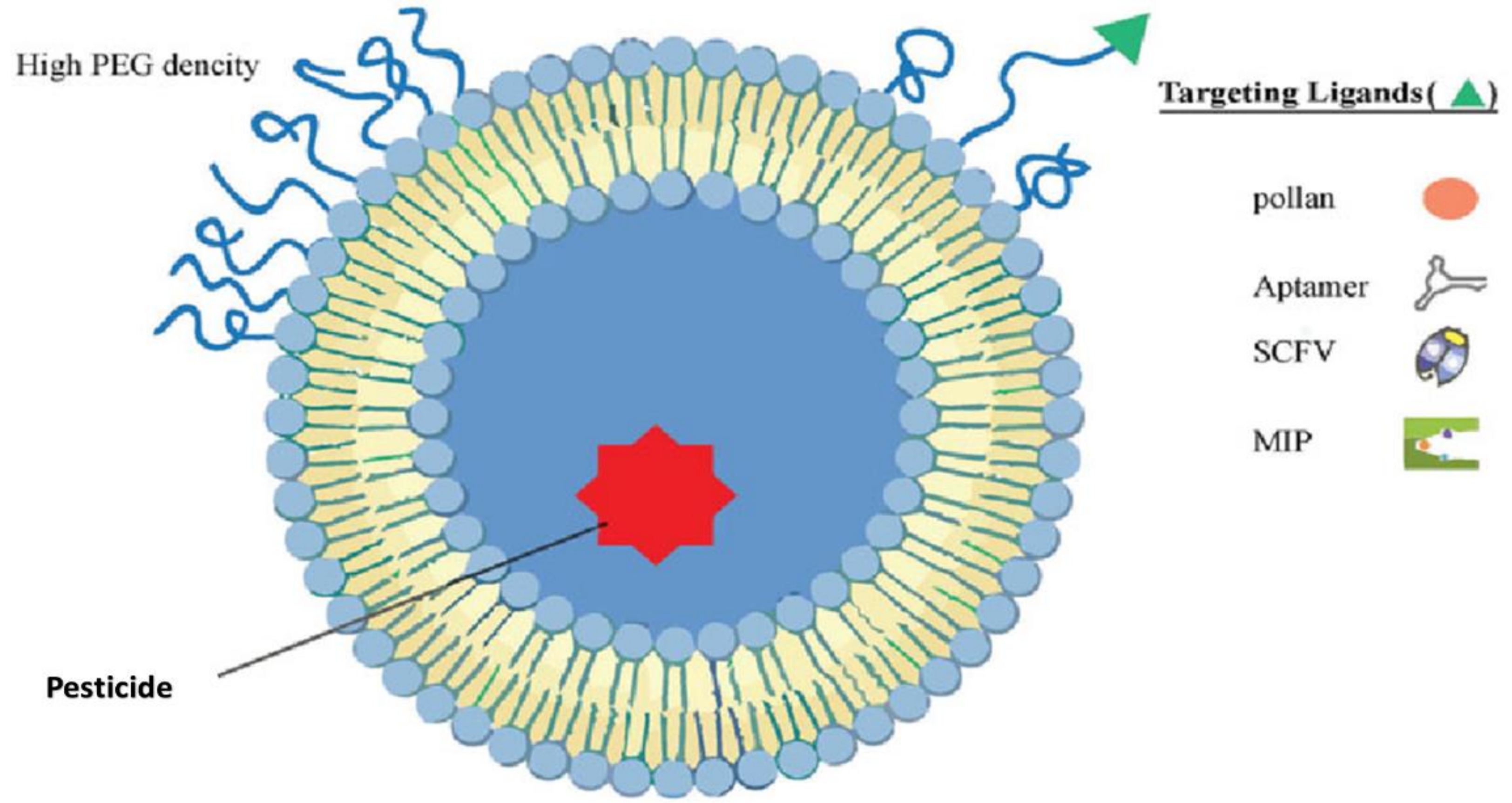
NLCs

Emulsions

- Spherical amphiphilic structures made from polar lipids
- Hydrophilic heads of the polar lipids are oriented towards water
- Hydrophobic tails are arranged towards the central core

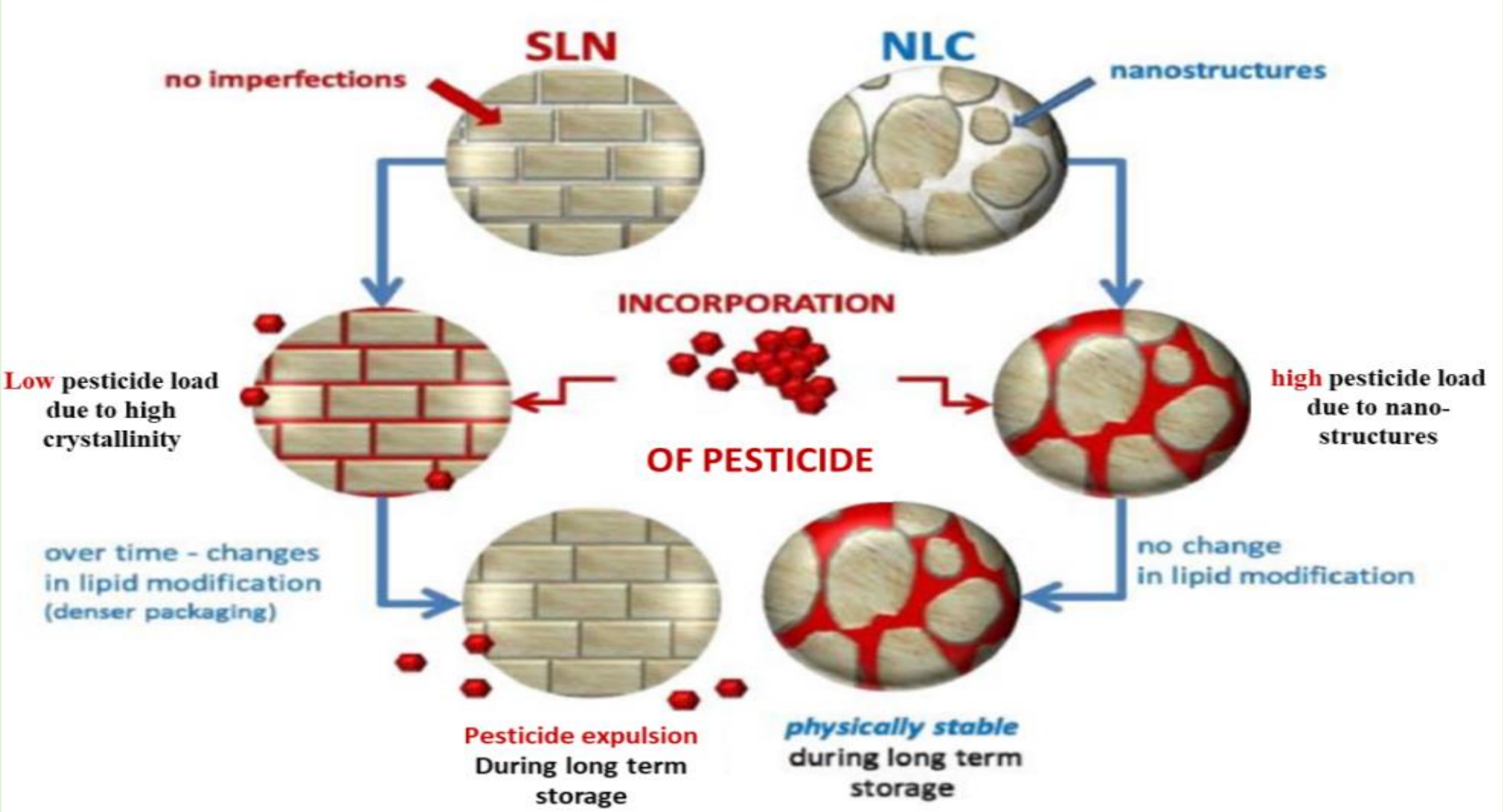
.

Nanoliposomes



- Formulated by solid lipids known as solid lipid nanoparticles (SLNs)
- Mixture of solid lipids and oils called nanostructured lipid carriers (NLCs)

Nanolipid Carriers: SLNs & NLCs



Nanoemulsions

- One of the simplistic and highly effective nutraceutical and pharmaceutical delivery systems in the encapsulation industry

- **Different techniques to preparation Nanoemulsions and Nanolipid Carriers**

a) Hot homogenization

b) Cold homogenization

c) High pressure homogenization

d) Solvent emulsification–evaporation

e) Solvent emulsification-diffusion

f) Microemulsion

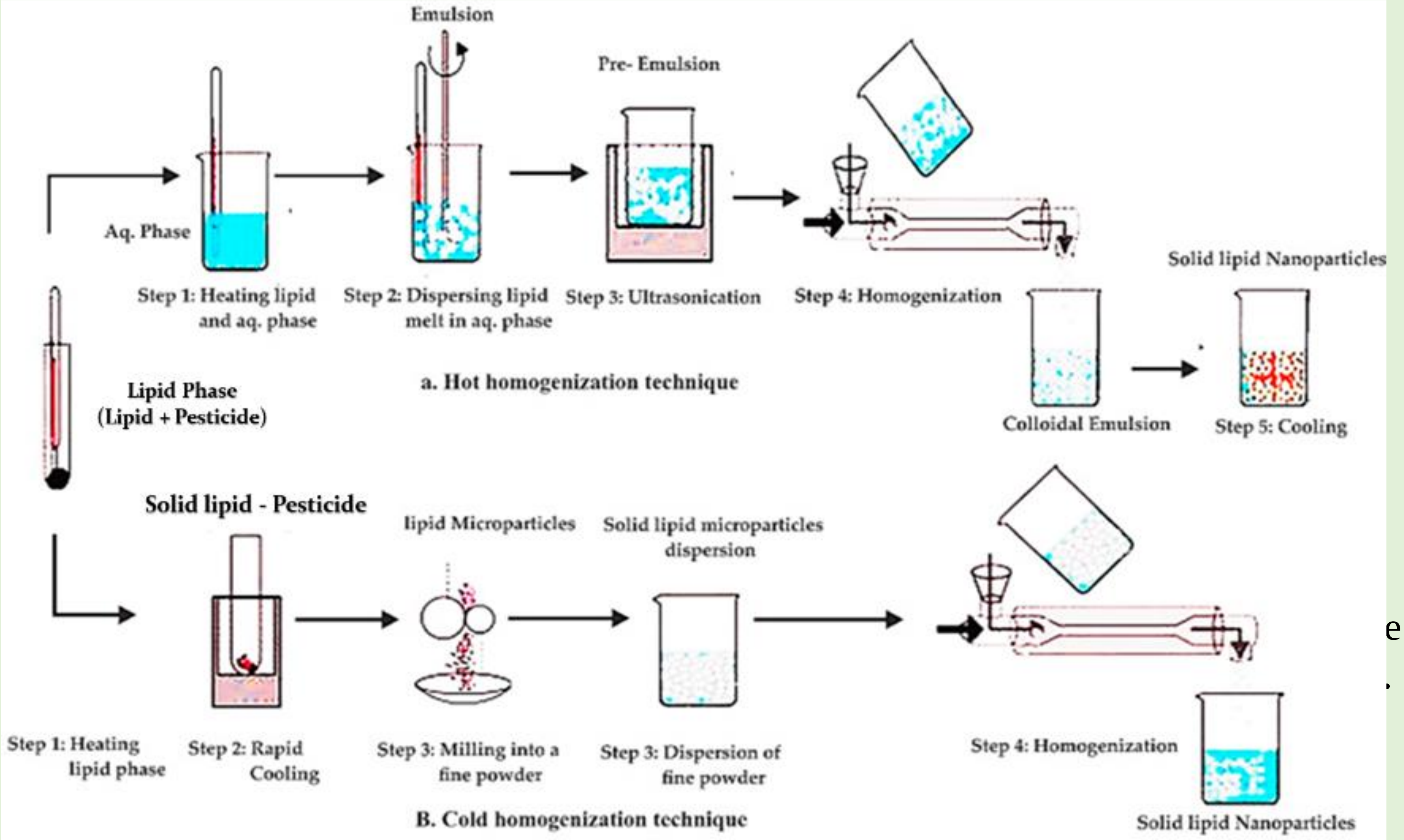
g) Melting dispersion

h) Ultrasonication

i) Solvent injection

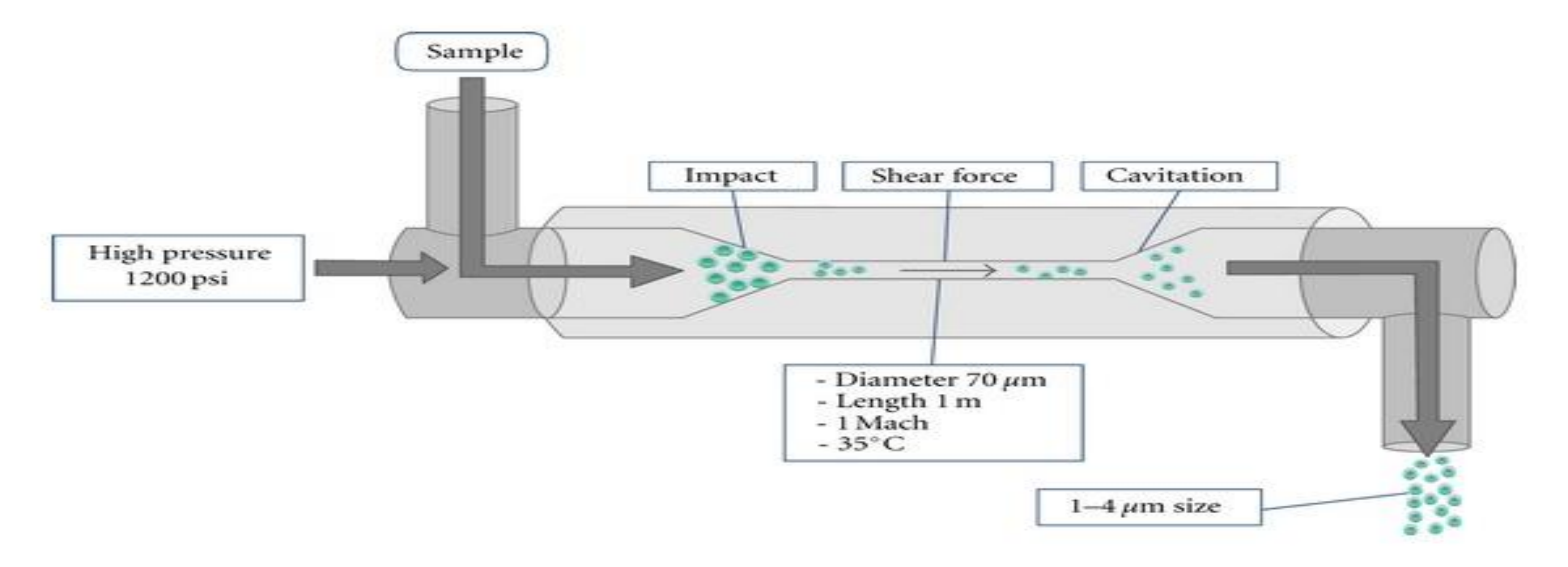
a) Hot

b) Cold


Emulsion
Pre- Emulsion
Aq. Phase
Step 1: Heating lipid and aq. phase
Step 2: Dispersing lipid melt in aq. phase
Step 3: Ultrasonication
Step 4: Homogenization
Solid lipid Nanoparticles
Lipid Phase (Lipid + Pesticide)
a. Hot homogenization technique
Colloidal Emulsion
Step 5: Cooling
Solid lipid - Pesticide
lipid Microparticles
Solid lipid microparticles dispersion
Step 1: Heating lipid phase
Step 2: Rapid Cooling
Step 3: Milling into a fine powder
Step 3: Dispersion of fine powder
Step 4: Homogenization
Solid lipid Nanoparticles
B. Cold homogenization technique

c) High pressure homogenization

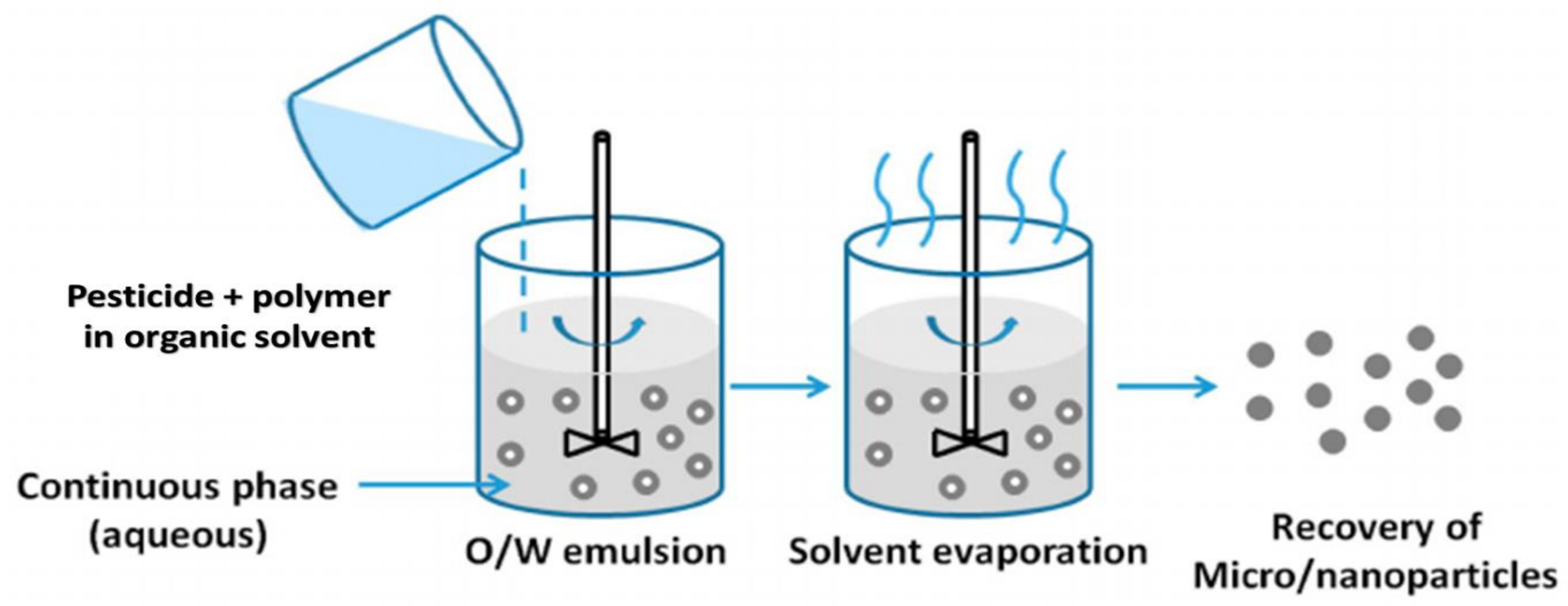
- The lipid is pushed through high shear stress under the influence of high pressure (100–2000 bar) which reduces the particle size to nano levels.



d) Solvent emulsification–evaporatio

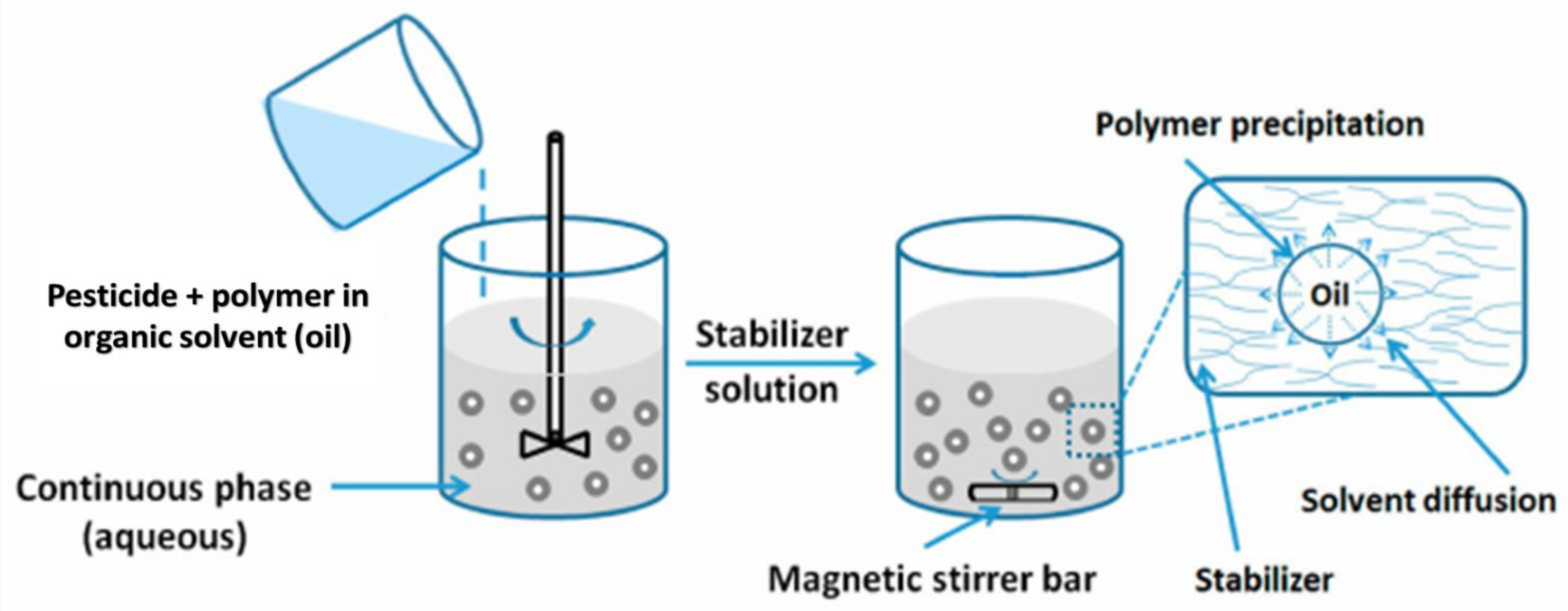
- The lipids and active component/agrochemicals are dissolved in an organic solvent and the solution emulsified in aqueous solution.

- The organic solvent is removed by evaporating the emulsion in a rotary evaporator at 50–60°C .



e) Solvent emulsification-diffusion

- The solvent and water are mutually saturated prior to dissolution of lipid and active component/agrochemical in water saturated solvent followed by stirring to yield O/W emulsion.



f) Microemulsion

- Agrochemical is dispersed in molten lipid to which mixture of water, co–surfactant and surfactant
- Preheated to the molten lipid temperature, are added and stirred gently

Oil

Water

Mixing

Magnetic Stirring homogenize

Co-Surfactant

Clear Solution

Construction of phase diagram

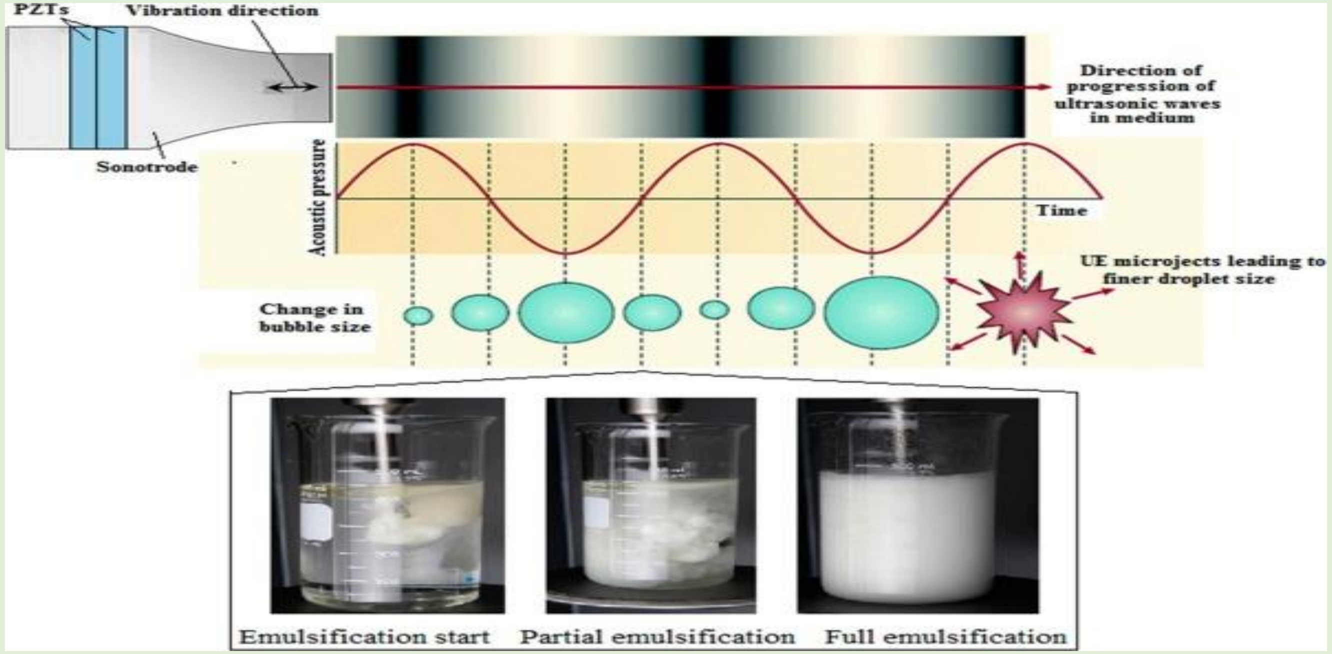
Microemulsion

g) Melting dispersion

- Agrochemical and solid lipid are melted in the presence of organic solvent that forms the oil phase.

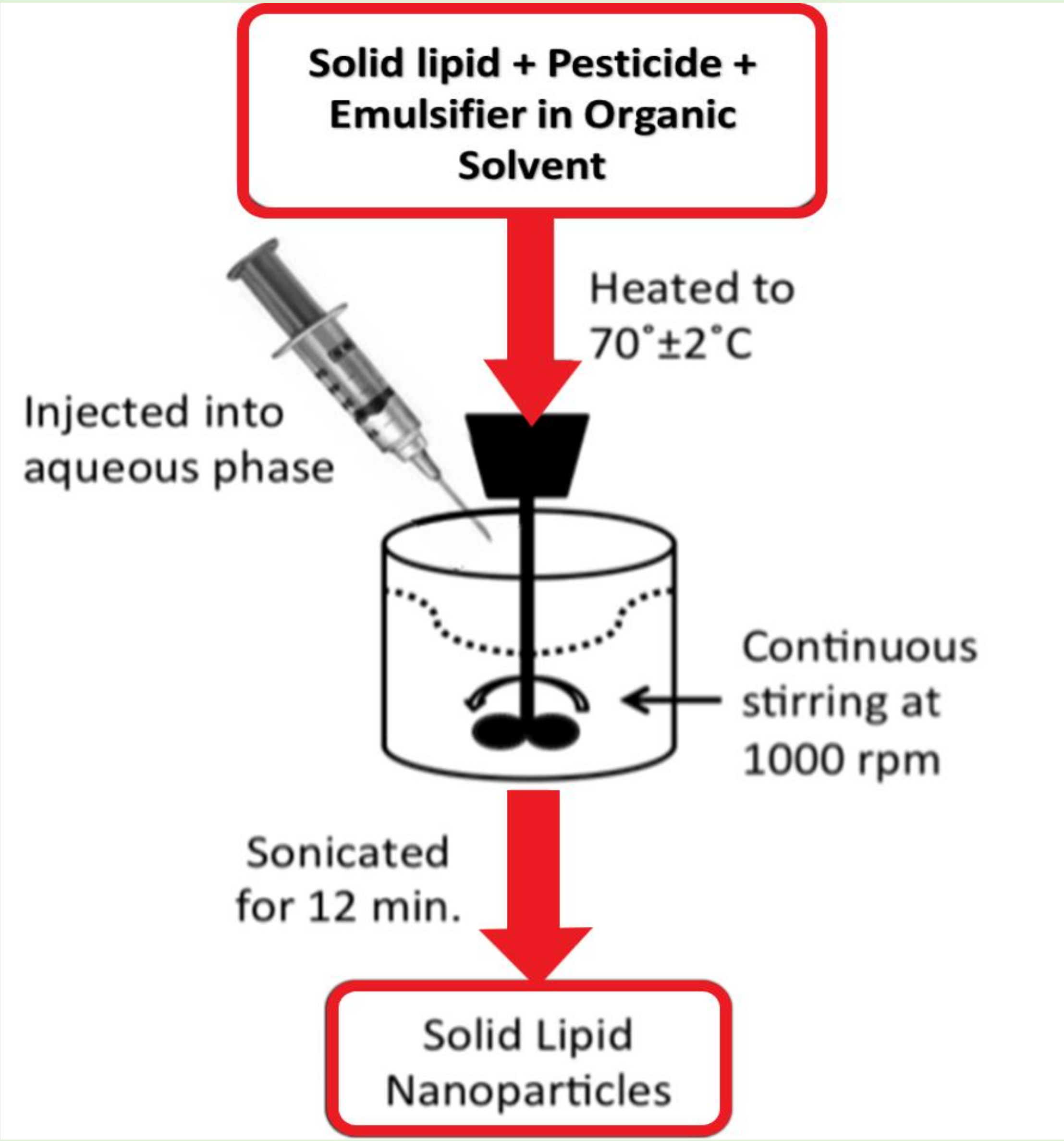
h) Ultrasonication

- The dispersion of molten core and phospholipids takes place in an aqueous medium at elevated temperatures through ultrasonication.



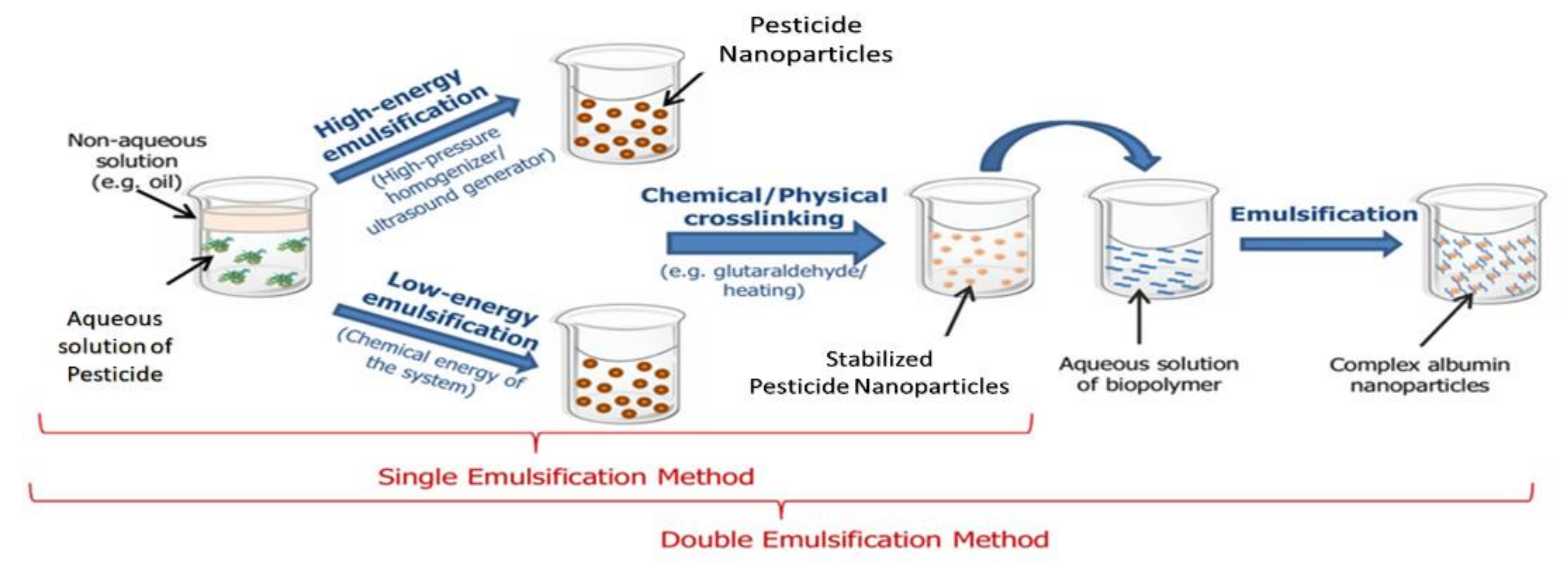
i) Solvent injection

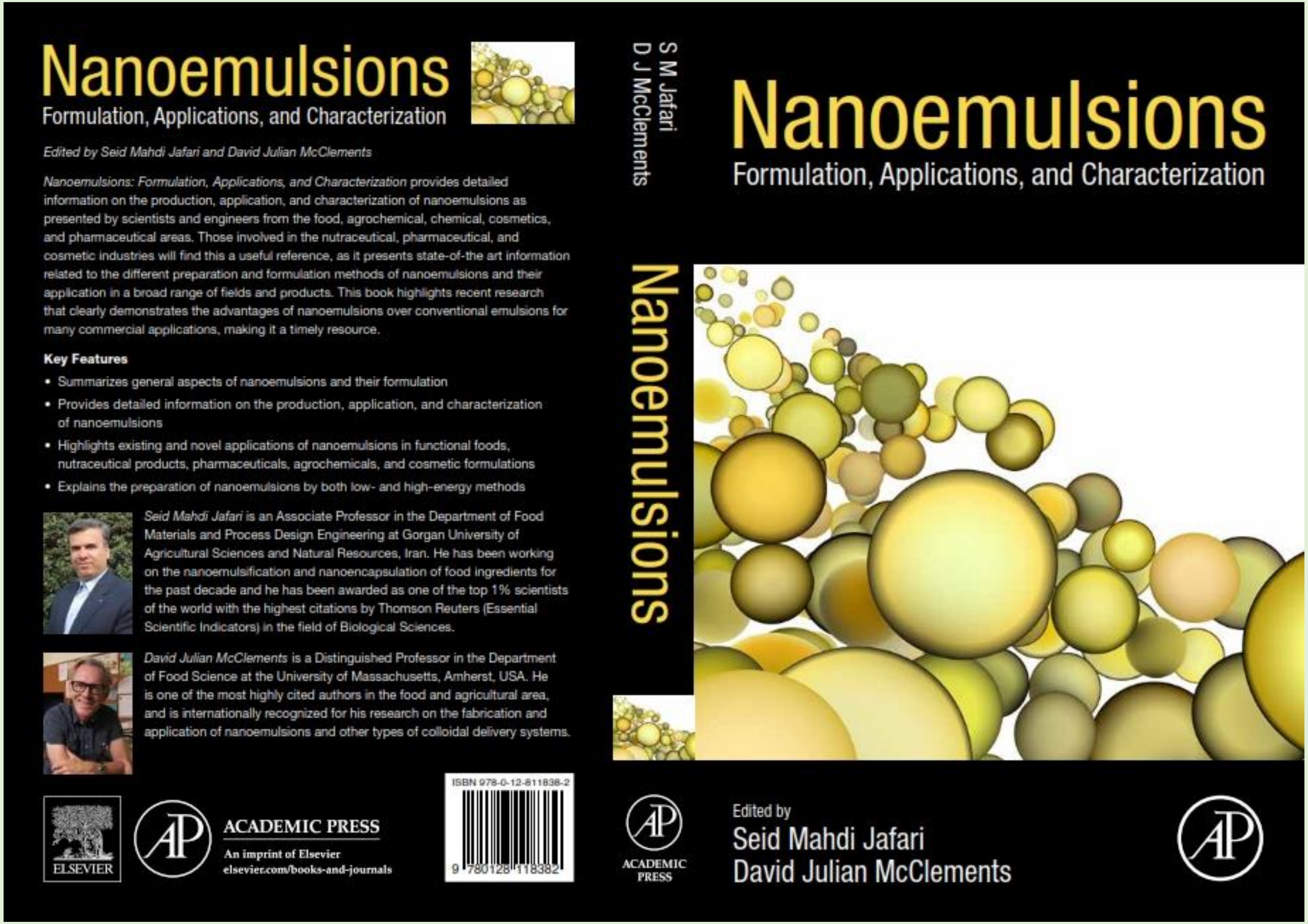
- The lipids and agrochemicals are solubilized in a water–miscible solvent or water–miscible solvent mixture
- Quickly injected into an aqueous phase of surfactants



j) Double emulsification

- A previously dissolved aqueous hydrophilic bioactive compound is mixed with molten lipid to form the primary emulsion
- Stabilized by adding stabilizer that is dispersed in an aqueous phase




Nanoemulsions
Formulation, Applications, and Characterization
Edited by Seid Mahdi Jafari and David Julian McClements
Nanoemulsions: Formulation, Applications, and Characterization provides detailed information on the production, application, and characterization of nanoemulsions as presented by scientists and engineers from the food, agrochemical, chemical, cosmetics, and pharmaceutical areas. Those involved in the nutraceutical, pharmaceutical, and cosmetic industries will find this a useful reference, as it presents state-of-the art information related to the different preparation and formulation methods of nanoemulsions and their application in a broad range of fields and products. This book highlights recent research that clearly demonstrates the advantages of nanoemulsions over conventional emulsions for many commercial applications, making it a timely resource.
Key Features
• Summarizes general aspects of nanoemulsions and their formulation
• Provides detailed information on the production, application, and characterization of nanoemulsions
• Highlights existing and novel applications of nanoemulsions in functional foods, nutraceutical products, pharmaceuticals, agrochemicals, and cosmetic formulations
• Explains the preparation of nanoemulsions by both low- and high-energy methods
Seid Mahdi Jafari is an Associate Professor in the Department of Food Materials and Process Design Engineering at Gorgan University of Agricultural Sciences and Natural Resources, Iran. He has been working on the nanoemulsification and nanoencapsulation of food ingredients for the past decade and he has been awarded as one of the top 1% scientists of the world with the highest citations by Thomson Reuters (Essential Scientific Indicators) in the field of Biological Sciences.
David Julian McClements is a Distinguished Professor in the Department of Food Science at the University of Massachusetts, Amherst, USA. He is one of the most highly cited authors in the food and agricultural area, and is internationally recognized for his research on the fabrication and application of nanoemulsions and other types of colloidal delivery systems.
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David Julian McClements

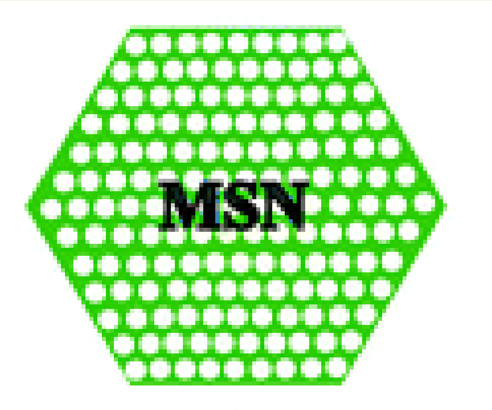
Porous Inorganic

Mesoporous Silica Nanoparticle

Porous Hollow Silica Nanoparticle

Soft template

Modified Stober method



Fast Self-assembling

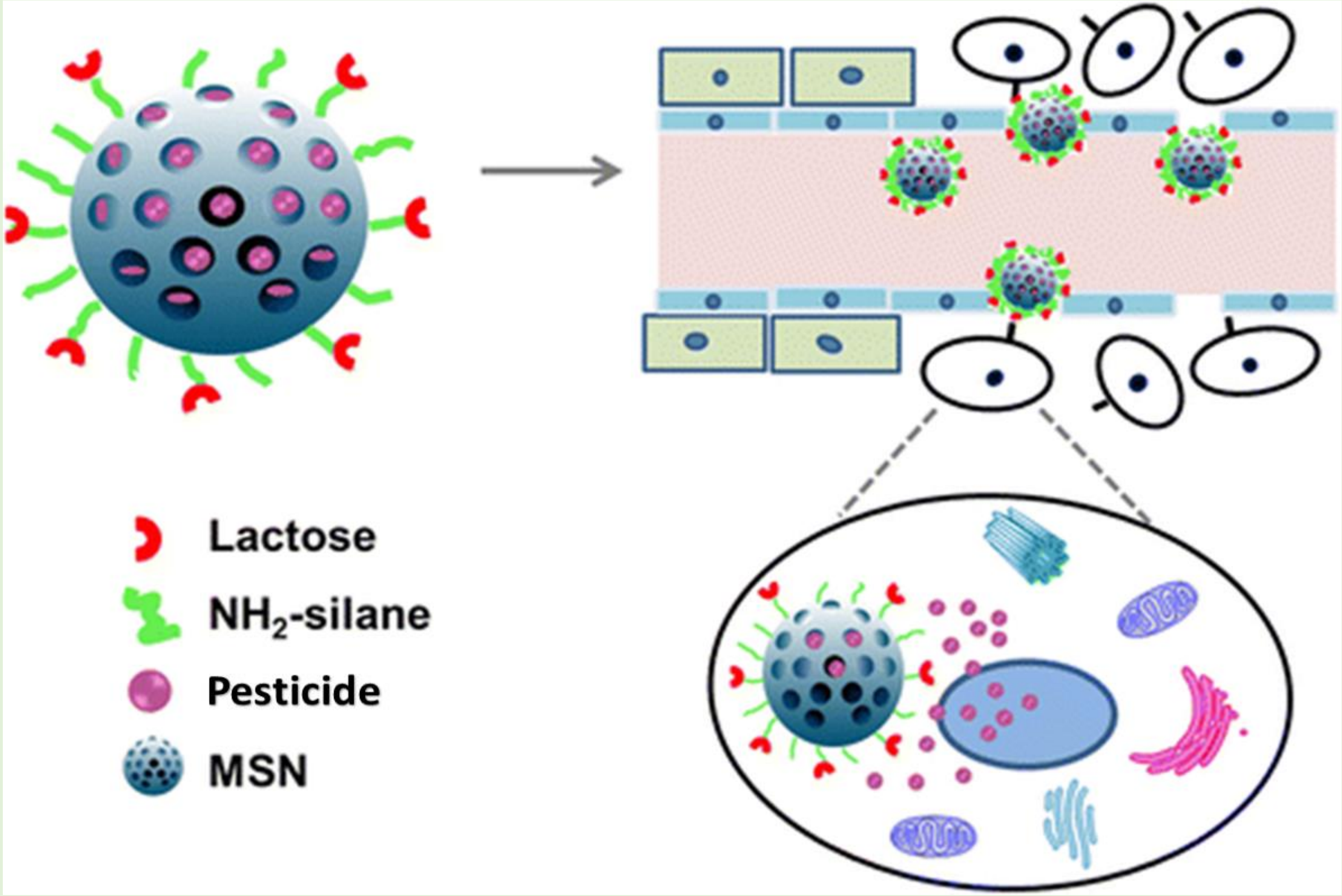
Hard template

Modified aerosol procedure

Dissolving & Reconstruction

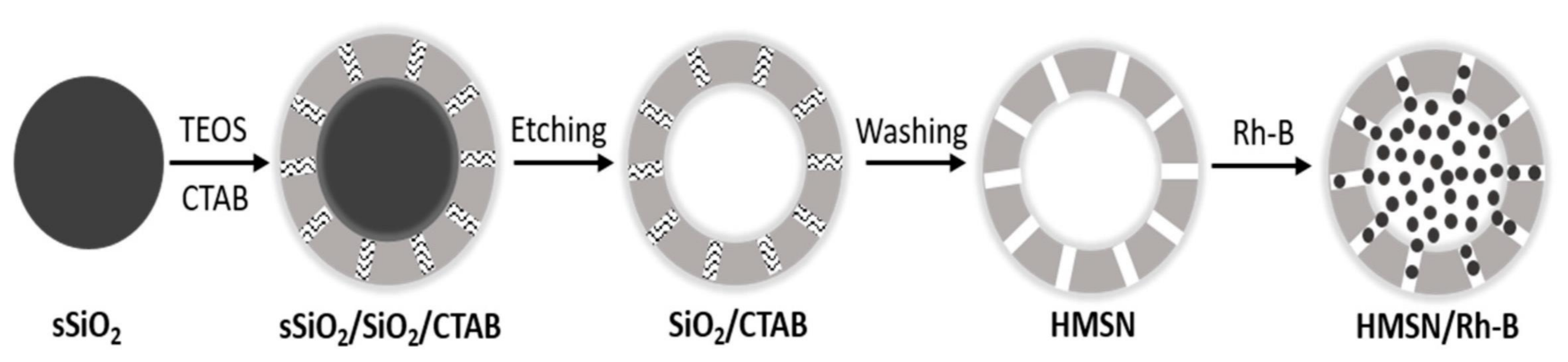
Mesoporous Silica Nanoparticle

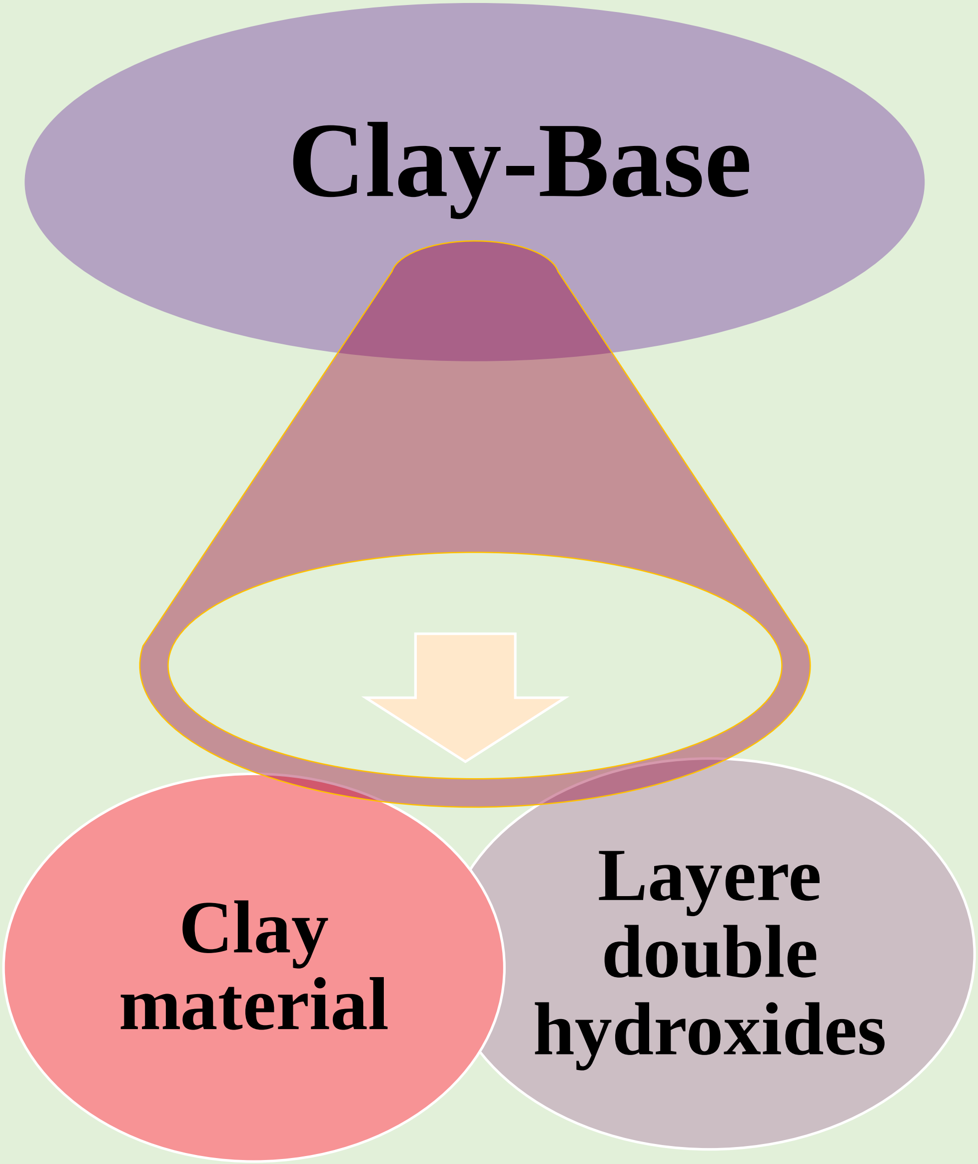
- The amphiphilic surfactant provides the basic structure on which the deposition and condensation of SiO2 take place.



Porous Hollow Silica Nanoparticle

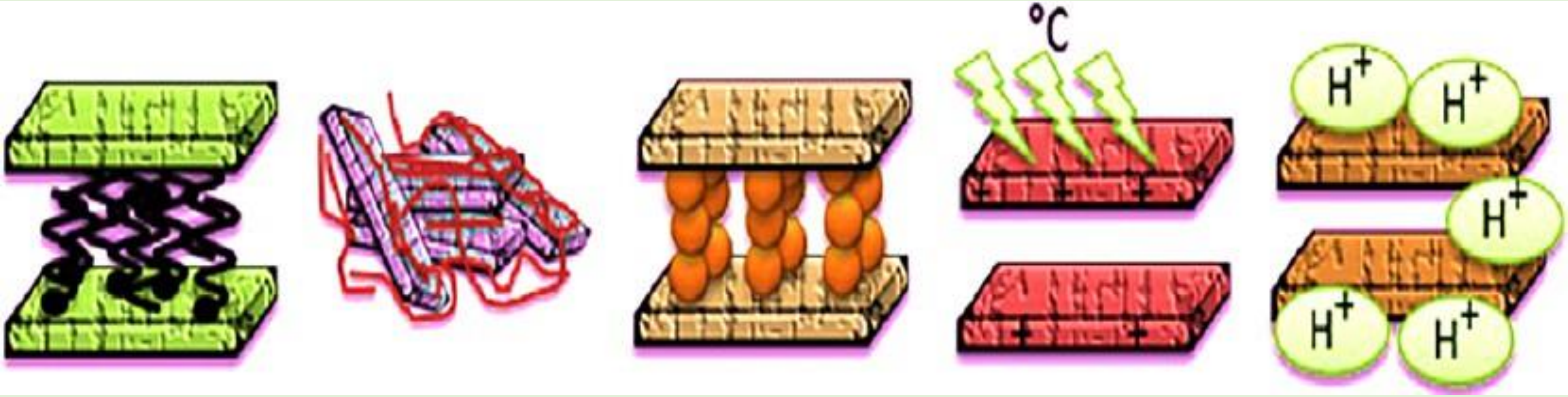
HSNs act as carrier materials for both oil-soluble and water-soluble pesticides, and loading efficiency depends on their morphological features. The pesticide loading efficacy can also be increased by improving the loading methods.




Clay-Base
Clay material
Layere double hydroxides

Clay material

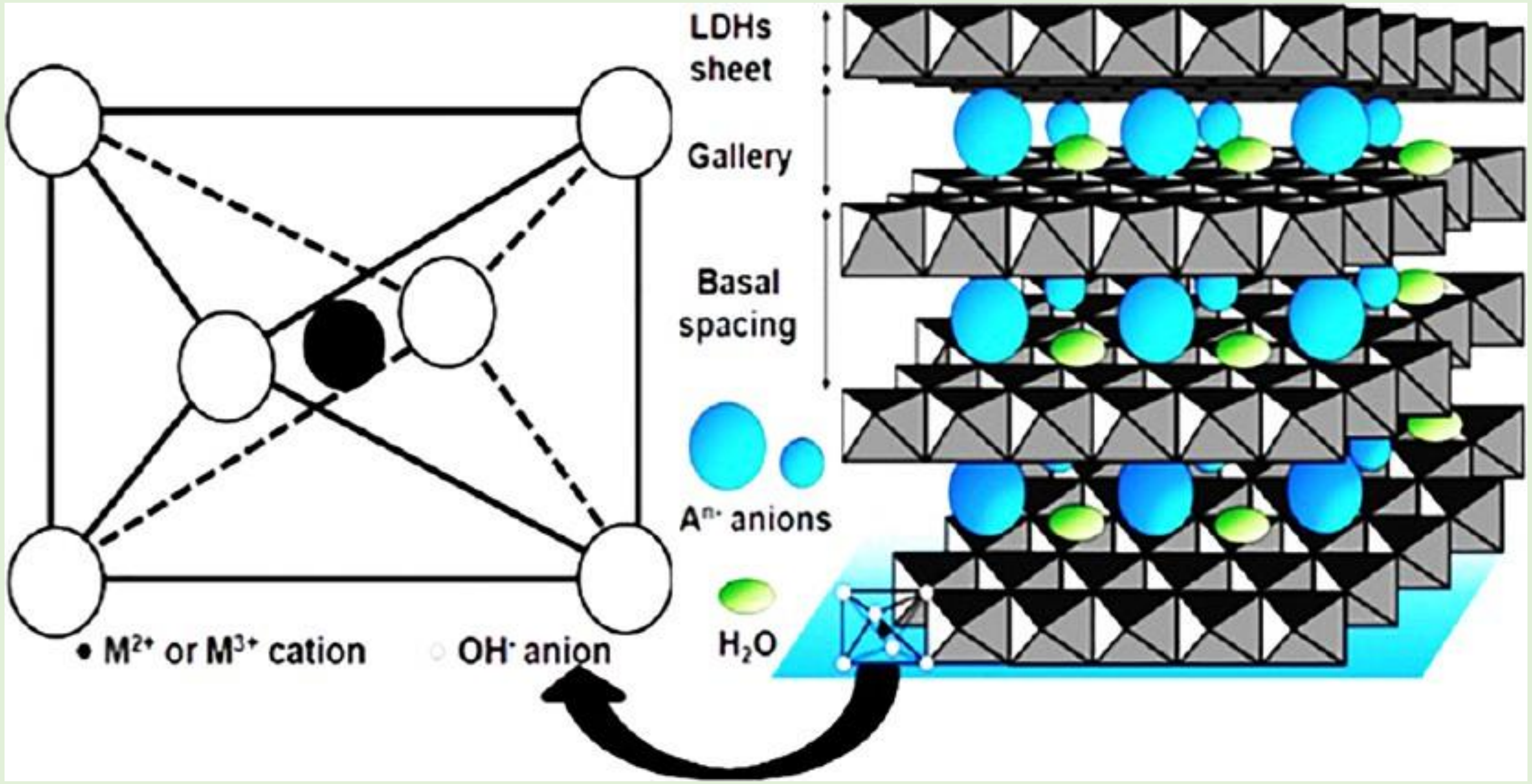
Nanoclays are fine-grained materials belonging to the wider group of minerals commonly described as naturally occurring aluminum silicates or hydrous silicates with sheet-like structures.



(a) Organoclay **(b)** Polymer-clay nanocomposite **(c)** Pillared clay **(d)** Heat-treated clay **(e)** Acidtreated clay

Layere double hydroxides

- Natural and synthetic materials of anionic lamellar compounds
- made up: positively charged brucite-type layers of mixed metal hydroxides



Other Nanoencapsulation Materials

Poly(citric acid) grafted carbon nanotube

Inorganic porous materials such as porous nano-$CaCO_3$, nano-zeolite

Niosomes

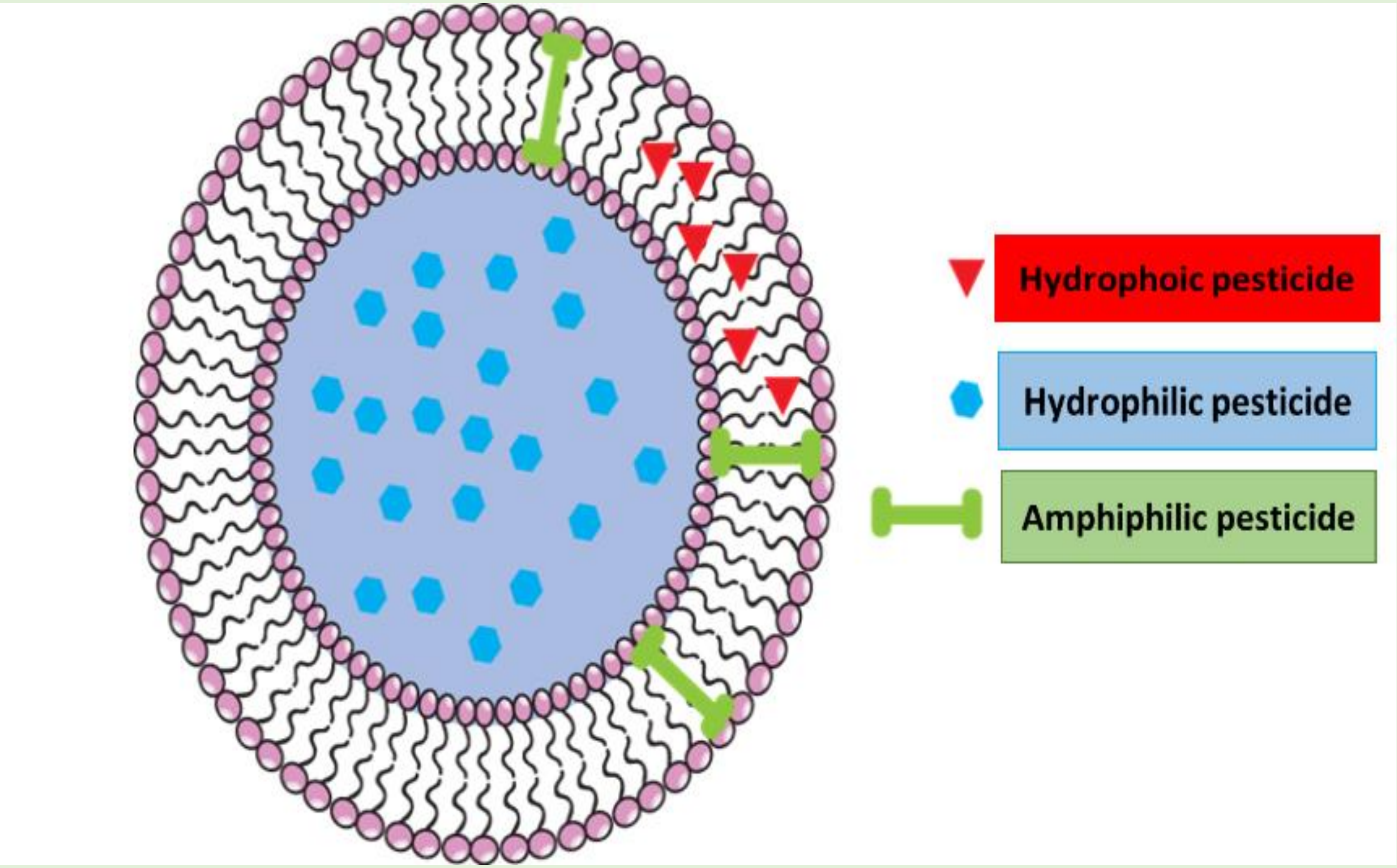
Dendrimers

Niosomes

- Self-assembled vesicular nanocarriers
- Obtained by hydration of synthetic surfactants and appropriate amounts of cholesterol or other amphiphilic molecules

- **Different methods of noisome preparation**

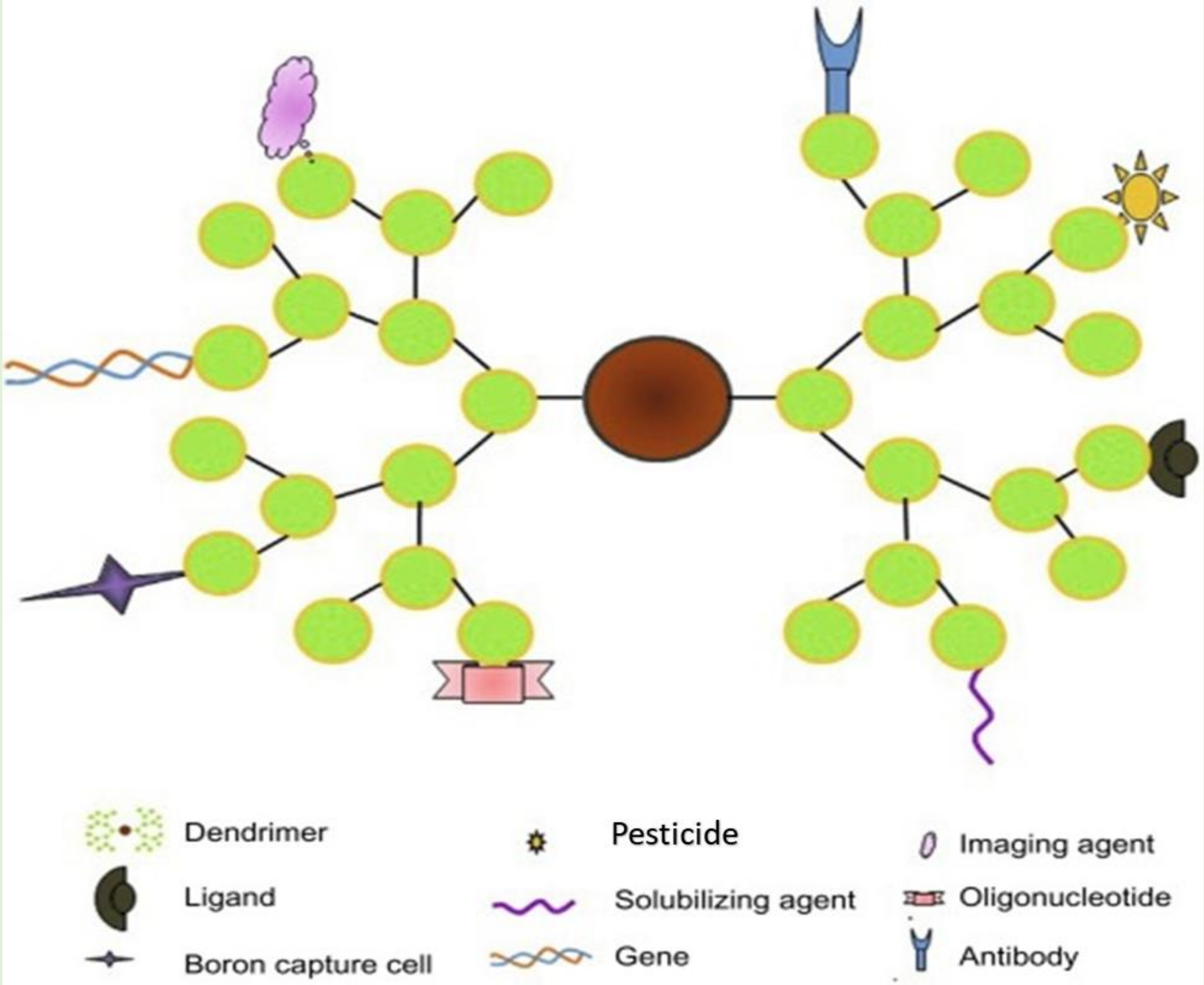
a) Ether injection
b) Trans membrane pH gradient method
c) Reversed phase evaporation
d) Bubbling of nitrogen
e) The single pass technique
f) Microfluidization
g) Thin film hydration
h) The Handjani-Vila method
i) Formation of niosomes from proniosomes
j) Melted amphiphile injection
k) Solid amphiphiles/hot water
l) Micellar solution/enzymes



Dendrimers

- Novel three-dimensional, symmetric and highly branched globular polymeric structures

- synthesized by repetitive addition of monomers from a central polyfunctional core



Application of Nanoencapsulated Agrochemicals in Practice

Nanoencapsulation Technologies

for the Food and Nutraceutical Industries

Edited by
Seid Mahdi Jafari

Nanoencapsulation is a novel area of research in the food industry being developed rapidly in recent years. *Nanoencapsulation Technologies for the Food and Nutraceutical Industries* supports this subject and discusses the methods applied in the entrapment of nutrients plus the latest practices in the industry. Edited by a leading scientist, this book is prepared for scholars active in the field of food, pharmaceutical and nutraceutical science, which is an essential reference in the field of nanoencapsulation techniques and a powerful resource for the future encapsulation and controlled release technologies.

Dr. Seid Mahdi Jafari received his PhD degree in Food Process Engineering from the University of Queensland (Australia), in 2006. He has been working on the nano-emulsification and nano-encapsulation of food ingredients for the past decade. Now, as an Associate Professor, he is an academic member of GAU (Iran). He has published more than 75 papers in top-ranked international Food Science journals and 15 book chapters along with editing 4 books with LAP and Elsevier publishers. In November 2015, he was awarded as one of the top 1% scientists of the world with the highest citations by Thompson Reuters (Essential Scientific Indicators) in the field of Biological Sciences.

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Nanoencapsulation Technologies for the Food and Nutraceutical Industries Seid Mahdi Jafari

Nanoencapsulation Technologies
for the Food and Nutraceutical Industries

Seid Mahdi Jafari

Nanoencapsulation of Food Bioactive Ingredients

Principles and Applications

In our previous book titled *Nanoencapsulation Technologies for the Food and Nutraceutical Industries* (Elsevier, 2017), we covered the nanoencapsulation techniques applicable to the food and nutraceutical industries plus their classification to make the foundation of next studies.

This book ***Nanoencapsulation of Food Bioactive Ingredients*** presents the cutting-edge research in the field of nanoencapsulation for different food bioactive components including phenolic compounds and antioxidants, vitamins, natural food colorants, fish oil and essential fatty acids, flavors, minerals, food antimicrobial agents and essential oils, enzymes, bioactive peptides, and biological molecules. The main goal of this book is to provide recent research activities of nanoencapsulation in the food industry based on special and categorized food bioactive components.

Dr. Seid Mahdi Jafari received his PhD degree in Food Process Engineering from the University of Queensland (Australia), in 2006. He has been working on the nanoemulsification and nanoencapsulation of food ingredients for the past decade. Now, as an associate professor, he is an academic member of GAU (Iran). He has published more than 85 papers in top-ranked International Food Science journals (h-index=23) and 18 book chapters along with editing 4 books with LAP and Elsevier publishers. In November 2015, he was awarded as one of the top 1% scientists of the world with the highest citations by Thompson Reuters (Essential Scientific Indicators) in the field of Biological Sciences.

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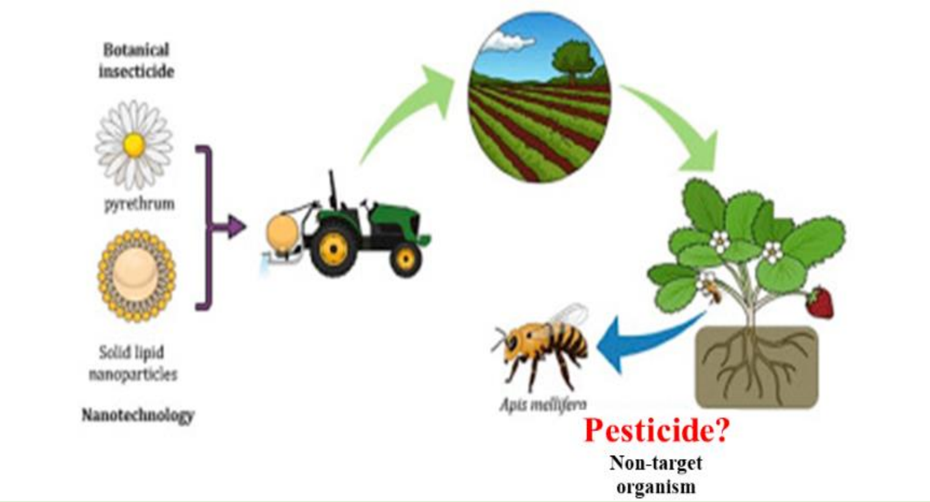
Nanoencapsulation of Food Bioactive Ingredients Seid Mahdi Jafari

Seid Mahdi Jafari
Nanoencapsulation of Food Bioactive Ingredients
Principles and Applications

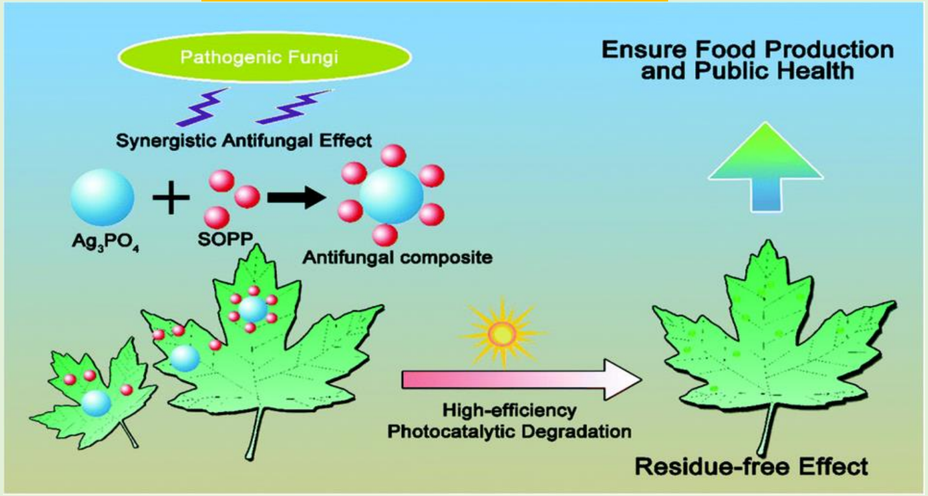
- ✓ Nanotechnology offers great potential to produce agrochemicals with the desired chemical composition and efficiency, thereby boosting the plant productivity.

Nanofertilizers

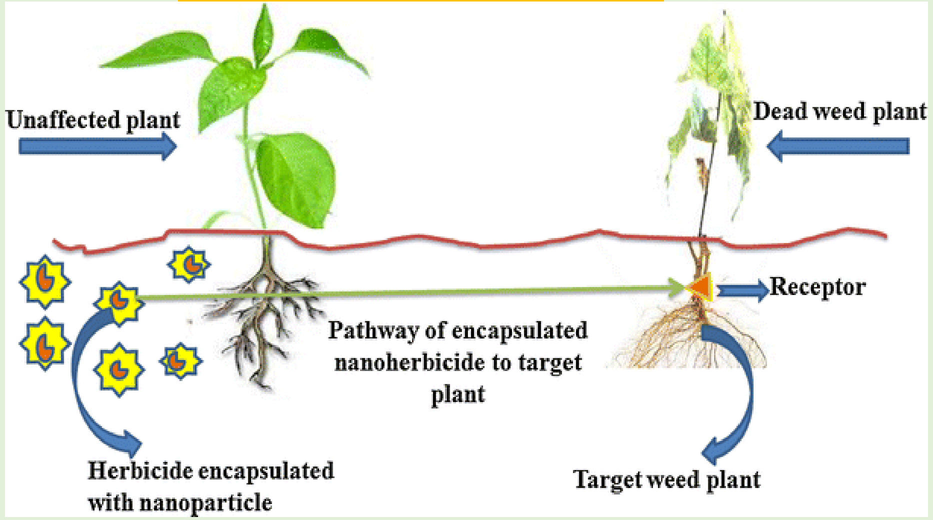
Nanopesticides



Nanofungicides



Nanoherbicides



Nanofertilizers

TABLE 1 Preparation and Properties of Nanofertilizers

Fertilizer	Host	Particle Size	Target	Result	Reference
NPK	Polysulfone	–	Slow release fertilizer	Decreased release rate from coated granules	Tomaszewska and Jarosiewicz (2006)
NPK	Sulfur	100 nm	Controlled release fertilizer	Strategically released urea and phosphate	Wilson et al. (2008)
NPK	Chitosan	78 nm	Controlled release fertilizer	Higher stability with the addition of nitrogen and potassium than phosphorus	Corradini et al. (2010)
Nitrogen	Biochar supported sodium alginate, cellulose acetate and ethyl cellulose	–	Controlled release fertilizer	Retardation of urea hydrolysis	González et al. (2015)
Bacillus sp. (PG01)	PBSU-g-AA/starch[a]	4-6.3 µm	Controlled release fertilizer	Controlled release of bacterial fertilizer	Wu (2008)
Raoultella planticola	Sodium bentonite and alginate	0.95–1.39 mm	Slow release microbial fertilizer	Controlled and sustained release	He et al. (2015)
KNO_3	Poly(AA-co-NaAA)/PEG[b]	–	Controlled release fertilizer	Concentration gradient dependent diffusion	Ganguly and Das (2017)
KNO_3	Grapheme oxide	10 µm	Slow release fertilizer	Exhibition of slow release behavior	Zhang et al. (2014)

[a] *Polybutylene succinate grafted acrylic acid/starch.*
[b] *Poly(acrylic acid-cosodium acrylate)/polyethylene glycol.*

Nanopesticides

TABLE 2 Preparation and Properties of Nanopesticides

Pesticide	Host	Particle Size	Target	Result	Reference
Avermectin	Porous hollow silica	15 nm	UV-shielding	UV-protection and slow release	Li et al. (2007)
Insecticide	Eudragit S100	135 nm	Aphid	Enhanced penetration in the plant	Boehm et al. (2003)
Gamma cyhalothrin	Solid lipid	0.73–100 µm	*Dysdercus cingulatus* nymphs and *Spodoptera littoralis* larvae	Reduced toxicity towards fish (*Brachydanio rerio*) and daphnia (*Daphnia magna*)	Frederiksen et al. (2003)
Imidacloprid	poly(citric acid) and poly(ethylene glycol) dendrimer	10–20 nm	*Glyphodes pyloalis*	Reduction in essential dosage of pesticide	Memarizadeh et al. (2014)
Imidacloprid	Polyethylene glycol	–	*Culex quinquefasciatus*	Encapsulated forms being more toxic due to controlled release of nanoparticles	Bhan et al. (2014)
Temephos	Polyethylene glycol	129.5 nm	*Culex quinquefasciatus*	Encapsulated forms being more toxic due to controlled release of nanoparticles	Bhan et al. (2014)
Copper selenide	Graphene oxide	20 nm	*Pieris rapae*	Drift resistance with targeted release for enhanced larval mortality	Sharma et al. (2017)
Azidobenzaldehyde	Carboxymethyl chitosan	98.6 nm	Armyworm larvae	Superior insecticidal activity of the nanocapsule	Sun et al. (2014)
Pulegone	Sunflower and Tween 80	62.0–548.7 nm	*Sitophilus oryzae* and *Tribolium castaneum*	Powerful bioactivity of the nanoemulsion	Golden et al. (2018)
Azadirachta indica oil	Tween 20	31.03 nm	*Culex quinquefasciatus*	Effective larvicidal properties	Anjali et al. (2012)
Deltamethrin	Chitosan-coated beeswax	<244.8 nm	Photodegradation	Protection of deltamethrin against photodegradation	Nguyen et al. (2012)
Silver	*Aspergillus flavus*	50 nm	*S. aureus, B. subtilis, E. coli* and *Trichoderma* spp.	Effective antimicrobial properties	Fatima et al. (2016)
Zinc oxide	*Aloe vera* gel	45–60 nm	*E. coli, K. pneumoniae, P. aeurginosa* and *S. aureus*	Activity against multi-resistant bacterial phytopathogens	Yadav et al. (2018)

Nanofungicides

TABLE 3 Preparation and Properties of Nanofungicides

Fungicide	Host	Particle Size	Target	Result	Reference
Tebucanazole/ chlorothalonil	Polyvinylpyridine and polyvinylpyridine-costyrene	100–250 nm	*Gloeophyllum trabeum*	Controlled release and high level protection against the fungus	Liu et al. (2001)
Copper (II)	Cetyl trimethylammonium bromide	3–10 nm	*P. destructiva*, *C. lunata*, *A. alternate* and *F. oxysporum*	Promising antifungal activity against plant pathogenic fungi	Kanhed et al. (2014)
Copper (II)	Hydroxyapatite	–	*Plasmopara viticola*	Efficient control of *Plasmopara viticola*	Battiston et al. (2018)
Zinc oxide	*Aloe vera* gel	45–60 nm	*A. alternata* and *F. oxysporum*	Activity against multi-resistant fungal phytopathogens	Yadav et al. (2018)
Silver	*Aspergillus flavus*	50 nm	*A. niger* and *Trichoderma* spp.	Effective antifungal properties	Fatima et al. (2016)

Nanoherbicides

TABLE 4 Preparation and Properties of Nanoherbicides

Herbicide	Host	Particle Size	Target	Nontarget	Result	Reference
Atrazine	Poly(epsilon-caprolactone)	483.1 nm	*Brassica* sp.	*Zea mays*	More effectiveness and less genotoxicity	Pereira et al. (2014)
Paraquat	Chitosan/ tripolyphosphate	420 nm	*Brassica* sp.	*Zea mays*	Less cytotoxicity and genotoxicity	Grillo et al. (2014)
3,4-Dichlorophenoxyacetate	Zinc-aluminum-3,4-dicholorophenoxyacetate	8.9–18.7 Å	–	–	Controlled release property in various aqueous media (phosphate > carbonate > sulfate > chloride)	Ghazali et al. (2013)
2,4-Dichlorophenoxy acetate	Starch/sodium alginate bead	16.80 μm	–	–	Slow release of the herbicide	Riyajan (2017)
Satureja hortensis essential oil	Tween 80 (O/W emulsion)	<130 nm	*Amaranthus retroflexus* and *Chenopodium album*	–	High phytotoxicity through interferes with the germination, growth and physiological processes of the weeds	Hazrati et al. (2017)

✓ Spraying of Cu(OH)2 nanopesticides in lettuce (Lactuca sativa),*(Zhao et al., 2016)*

- leaves increased K concentration in lettuce
- The accumulated Cu results in generation of ROS,against which the plant uses osome metabolites
- This reduces its total antioxidant capacity

✓ Nanoparticles of Zn and ZnO concentration 0.1 mg/L *(Wu et al., 2018).*

- Inhibit the nitrification rate of nitrifying bacterial communities, indicating their toxicity

✓ Studies on the accumulation and excretion/detoxification of biocompatible magnetic fluid of carbon-coated nanoparticles in pea, sunflower, tomato, and wheat *(Cifuentes et al., 2010).*

- Have revealed that nanoparticles reach the vascular tissue through the root and spread to the aerial part of the plants in <24 h using the transpiration phenomenon

Future Prospects of Nanoencapsulation in Agriculture

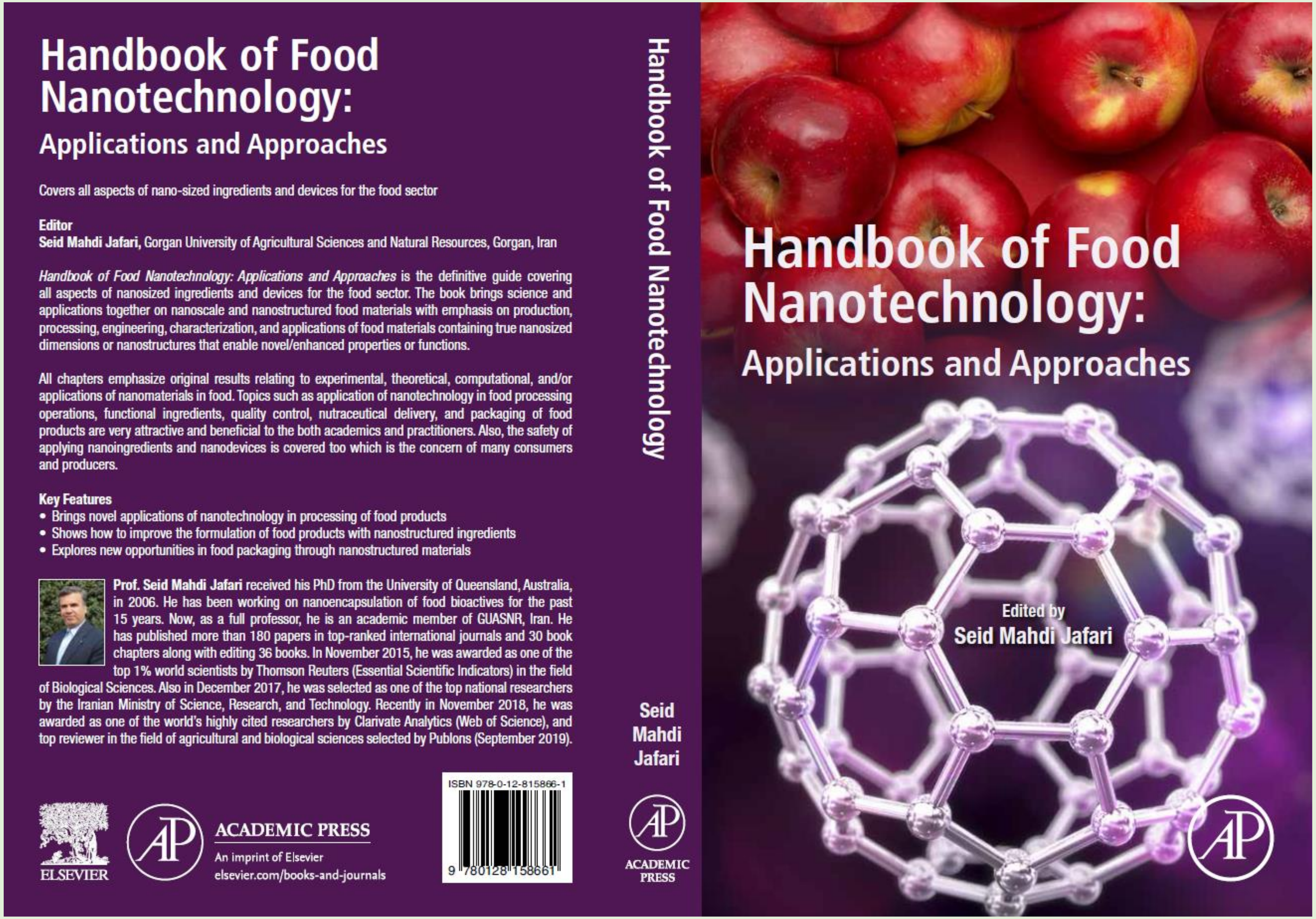
Bulk Pesticides

- Increase resistance in insects
- Insoluble in water
- More persistence, Higher toxicity to non- target Species

Nanopesticides

- Higher dispersion
- Solubility
- Lower toxicity to non target species
- Lower residual pollution

- ✓ As such, the use of fertilizers, pesticides, and other agrochemicals has increased enormously throughout the world.
- ✓ it is well established that a maximum (>90%) of the agrochemicals sprayed go waste.
- ✓ Production of nanoagrochemicals work with the basic principles of nanotechnology involving encapsulation of the active ingredient in a suitable carrier material for controlled release and targeted delivery of the nanoscale active ingredients


Handbook of Food Nanotechnology:
Applications and Approaches
Covers all aspects of nano-sized ingredients and devices for the food sector
Editor
Seid Mahdi Jafari, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran
Handbook of Food Nanotechnology: Applications and Approaches is the definitive guide covering all aspects of nanosized ingredients and devices for the food sector. The book brings science and applications together on nanoscale and nanostructured food materials with emphasis on production, processing, engineering, characterization, and applications of food materials containing true nanosized dimensions or nanostructures that enable novel/enhanced properties or functions.
All chapters emphasize original results relating to experimental, theoretical, computational, and/or applications of nanomaterials in food. Topics such as application of nanotechnology in food processing operations, functional ingredients, quality control, nutraceutical delivery, and packaging of food products are very attractive and beneficial to the both academics and practitioners. Also, the safety of applying nanoingredients and nanodevices is covered too which is the concern of many consumers and producers.
Key Features
• Brings novel applications of nanotechnology in processing of food products
• Shows how to improve the formulation of food products with nanostructured ingredients
• Explores new opportunities in food packaging through nanostructured materials
Prof. Seid Mahdi Jafari received his PhD from the University of Queensland, Australia, in 2006. He has been working on nanoencapsulation of food bioactives for the past 15 years. Now, as a full professor, he is an academic member of GUASNR, Iran. He has published more than 180 papers in top-ranked international journals and 30 book chapters along with editing 36 books. In November 2015, he was awarded as one of the top 1% world scientists by Thomson Reuters (Essential Scientific Indicators) in the field of Biological Sciences. Also in December 2017, he was selected as one of the top national researchers by the Iranian Ministry of Science, Research, and Technology. Recently in November 2018, he was awarded as one of the world's highly cited researchers by Clarivate Analytics (Web of Science), and top reviewer in the field of agricultural and biological sciences selected by Publons (September 2019).
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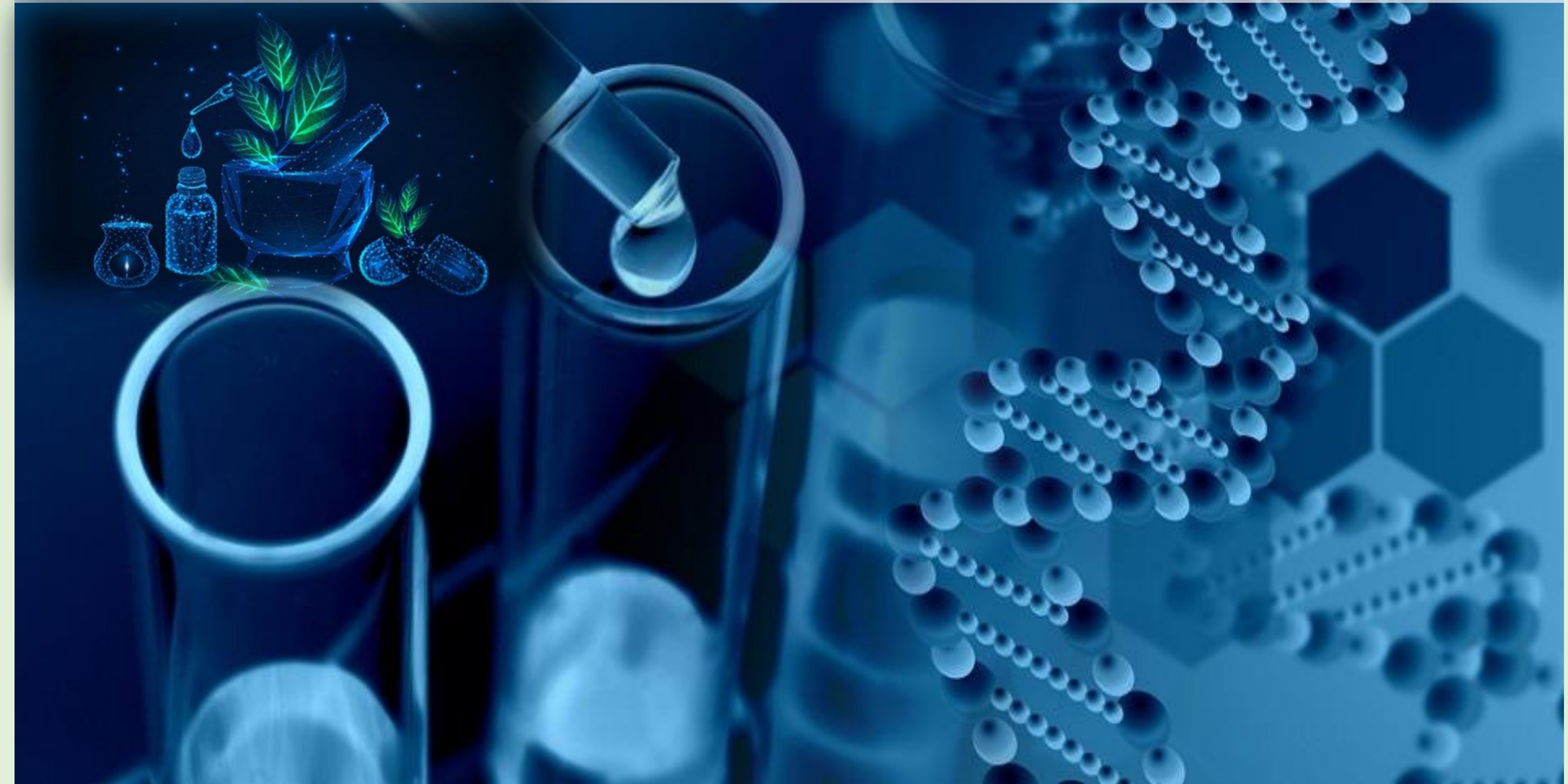
Thanks for your attention



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