Chapter

Vital Role of IPFT in Development of New-Generation Pesticide Formulation for Crop Protection: Advancement Overview in Asian Countries

Nusrat Iqbal, Amrish Agrawal, Md. Imteyaz Alam and Jitendra Kumar

Abstract

The agricultural sector of Asian countries supports 60% of the global population, accounting one-fifth of the world's agricultural land. Despite the gap between demand and supply of food is gradually increasing due to the damages caused by insect and other pest attacks on the limited agricultural land, the pest attack has influenced the entire agriculture sector either directly or indirectly, causing socioeconomic losses. To combat, farmers have been using conventional agrochemicals nonjudiciously that lead to adverse effects such as pesticide resistance, environmental contamination, and non-target toxicity. In this regard, new-generation agrochemical formulation techniques are advantageous over conventional pesticides and play a vital role in sustainable agriculture by fulfilling the demand of over-rising food supply to feed the increasing population. These formulations exhibit desired bio-efficacy at lower doses and have minimum possibility to leave pesticide residues in crop products and the environment. Institute of Pesticide Formulation Technology (IPFT), Gurugram, is one of the leading institutes in Asia, which is actively engaged in developing new-generation formulations to deliver safer, efficient, and environment-friendly pesticide formulations. So far, IPFT has developed 60 pesticide formulations and transferred technologies to different agrochemical industries globally. The new-generation formulations developed by IPFT mainly include microemulsion, nanoemulsion, capsulated suspension, nano-encapsulation, an emulsion in water, mixed formulations including several botanical pesticide formulations. The new advancement in pesticide delivery systems is very supportive in combating the crisis faced by the agricultural sector. In this chapter, formulation of different new-generation pesticides and their advancement are summarized.

Keywords: agriculture, agrochemicals, pesticides, new-generation formulations, pest, environment protection, user-friendly, crop protection

1. Introduction

Pesticides are the integral and significant part of modern agriculture. Pesticide usage is incredibly valuable for increasing food production in fulfilling the demand

of over-rising population. It has been previously stated by Webster et al. [1] that without pesticide use considerable economic losses will occur. The application rate of agricultural pesticides has swiftly augmented in different developing and developed countries [2]. Therefore, pesticides help in significant increase of yield and prevent the crop losses due to pest and pathogen attack. Application in a smaller quantity gives positive results but large quantity causes negative effect on environment, human health, and other beneficial organisms such as insects responsible for pollination [3]. However, non-judicious use causes various detrimental effects on environment and damages the ecosystem including economic loss of the farmers.

In formulated forms, pesticides are effective in very small quantity. There are many conventional pesticide formulations available in the market, which are being marketed and used in Asian countries in the form of dustable powder (DP), wettable powder (WP), emulsifiable concentrate (EC), soluble liquids (SL), etc. These conventional formulations are effective but due to certain limitations such as toxicity, cost, pest resistance, environmental contamination, death of beneficial organisms (e.g., honey bee), and human health problems they attracted interests toward advanced and safer pesticide formulation techniques [4]. Interestingly, in past 1990s, Asian countries explored certain new-generation formulation, which were solvent free, long lasting, safe and caused no effect on non-target organisms [5, 6].

With the advancement of new formulation technologies in Asian countries, many new-generation formulations have been developed to maintain a special place in international markets. In Asian countries, government supports the pesticide supply for the enhanced food production but its overuse (conventional formulations) has resulted in pesticide residue problem causing non-target and ecosystem toxicity.

In order to improve the safety of the user and ecosystem from the hazardous pesticides, Institute of Pesticide Formulation Technology (IPFT), India, has been engaged in developing new-generation formulations of synthetic as well as botanical pesticides. This chapter summarizes all the formulation advancement developed by IPFT for the safe and smart delivery of pesticide and reduces the adverse effects associated with conventional formulations.

2. Basic concept of formulation

A pesticide is the main active ingredient (actual chemical that controls pest population), which may be of synthetic chemical or botanical origin. Various chemical- and botanical-based pesticides have different physical and chemical characteristics such as solubility, viscosity, and physical state. Moreover, different pesticides act differently for various types of pest populations; for instance, some are effective for crawling insects, while the others are for flying insects. If a farmer uses active ingredient in pure form, he will face assured difficulties as follows:-

i. Active pesticide in unformulated form cannot spread evenly.

ii. In pure form, pesticides show phytotoxicity and toxicity toward non-targets. Pesticide in unformulated form environment-related hazards will enhance.

iii. After formulation development, application process is easy and convenient.

To resolve all these issues, formulation scientists formulate the active ingredient into different forms. As per the Knowles, "A pesticide formulation is a mixture of active ingredient with different inert materials to improve its stability during storage, easy handling, improves safety, application, or effectiveness towards pest population" [5].

3. Conventional formulations and their limitations

In Asia and Pacific regions, the most common formulations being used are dustable powders, emulsifiable concentrates, wettable powders, granules, soluble liquids, etc., for the control of insect pest and many pathogenic diseases [7, 8]. The most common conventional formulations are discussed below:

1. **Dust formulations**:-These formulations are for contact action pesticides. These formulations are ready to use and no need for dilutions before application. They contain very low active ingredients (usually 1–10%). The inert ingredient mainly contains talc, ash, silica, bentonite, etc. (**Figure 1**). These are always applied as dry and can drift easily to non-targets. These formulations are mainly used for cracks and crevices.

2. **Granules (GR):** Granular pesticide formulation mesh size is higher as compared with dust. As per the British standard, mesh size is (250–1050 microns). For sufficient activity, at least 90% granules should be in the range of British standards. Due to larger size, drift velocity decreased and less wastage occurs over due to dust formulations [9]. In granular formulation, pesticide is encrusted onto or wrapped up in absorptive particles of silica, sand, clay, and shells of walnut or corn cobs pieces, etc., as carrier materials. Granular formulations are most suitable for pre-emergence herbicides and soil insecticides (**Figure 2**).

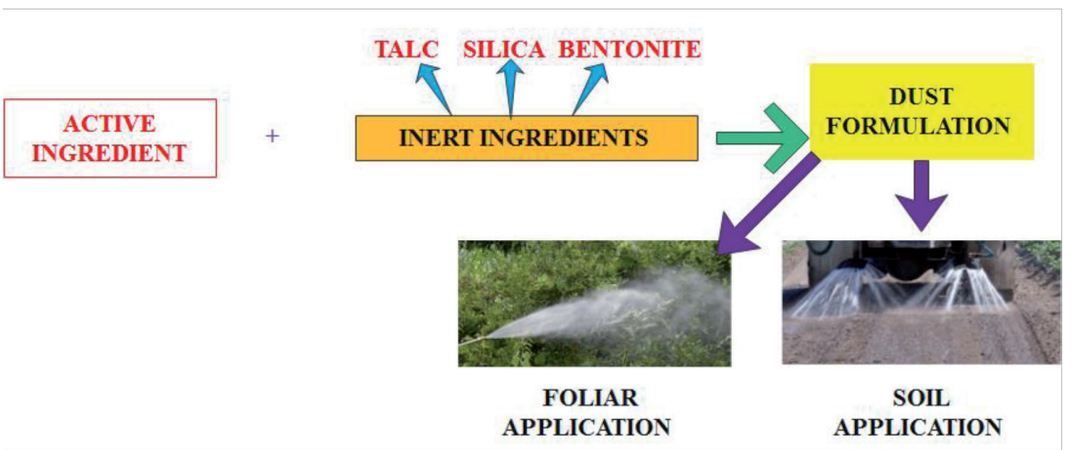

Figure 1.
Schematic illustration showing key steps involved in dust formulation and its mode of application.

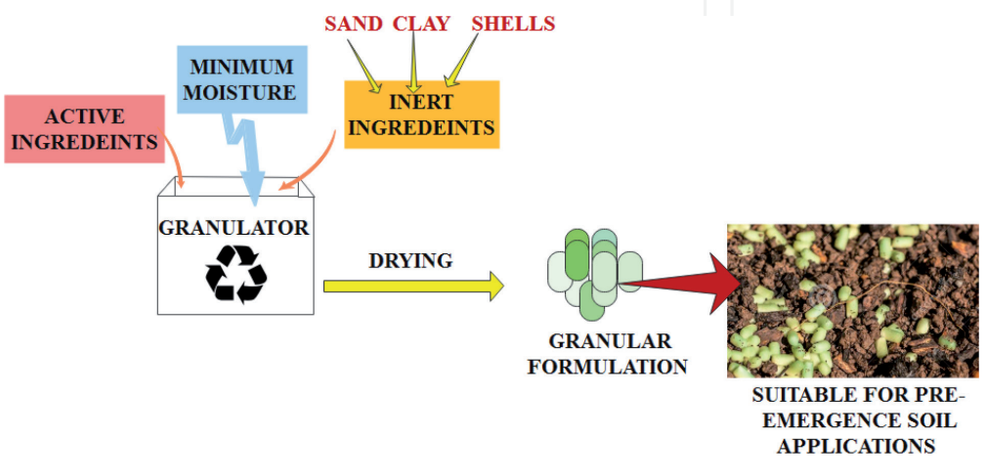

Figure 2.
Schematic representation showing key steps involved in granular formulation and its application.

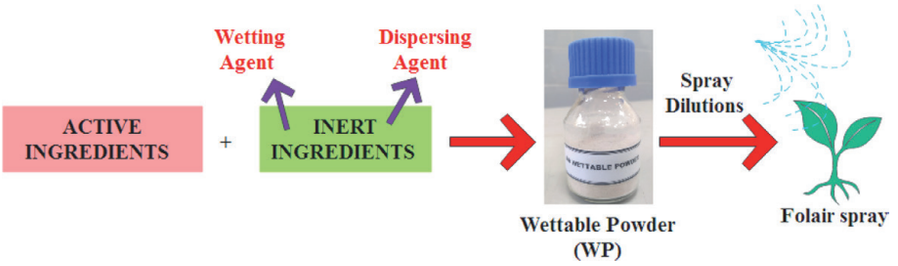

Figure 3.
Diagrammatical representation showing steps involved in WP formulation and its application.

3. **Wettable powder (WP):**-A WP contains active ingredient (pesticide) in a finely ground form along with wetting agents or dispersing agents (**Figure 3**). Wettable powders are applied by sprayers after diluting in water in the form of dilute suspensions. Wettable powders are safe to use, storing, and transporting.

4. **Soluble powders (SP):** In SP formulation, active ingredient or pesticide is mixed with the inert ingredients, which enhances the solubility of pesticide after dissolution in water (**Figure 4**). These SP formulations are easy to produce, economical, and stable under various temperature conditions.

5. **Emulsifiable concentrates:** Emulsifiable concentrate formulations are most common and popular formulation in Asian countries. These formulations are

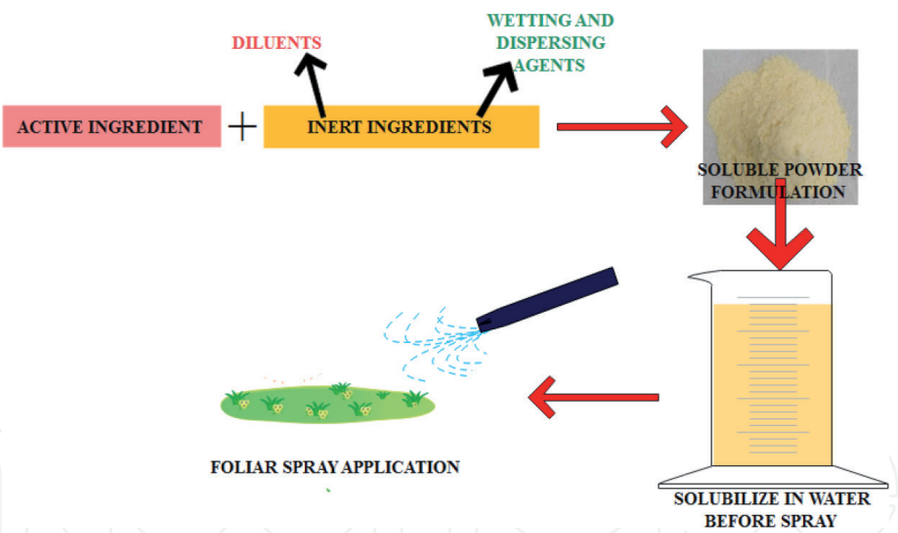

Figure 4.
Schematic representation showing key steps involved in soluble powder formulation and its application.

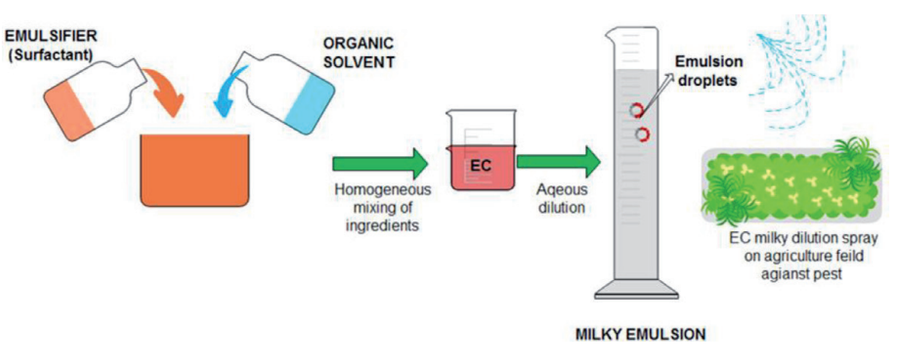

Figure 5.
Schematic representation showing key steps involved in EC formulation and its application.

suitable for the low melting point active ingredients, which are highly soluble in organic solvents. These formulations are developed by dissolving active ingredients in organic solvents along with emulsifying surfactants (**Figure 5**).

The main limitation is linked with the organic solvents that are mainly petroleum solvents being used in Asian countries. These petroleum solvents make the formulation flammable and cause dermal toxicity to the user. To rectify the problem associated with these conventional formulations, new formulations have been developed, which are improved and advance in terms of user and environment safety.

The major objectives of IPFT (India) to develop new formulation technologies are as follows:

1. To make the formulation techniques of different pesticide easy and convenient application.

2. To make pesticide formulations labor saving.

3. To prepare safer formulations for user and environment.

4. To reduce the toxicity of pesticides toward non-targets.

5. To minimize environmental contamination.

6. To enhance bio-efficacy against different types of pests.

7. To make the formulation economical and lower the frequency of applications.

4. Recent advancements in agrochemical formulations

Water-dispersible granules (WDG):-A WDG formulation is also termed as dry flowables (DF). These WDG formulations are non-dusty and disperse easily in water when added in spray tanks for its finer particle size in suspension. These are the safer and targeted delivery system for the various pesticides. Main uniqueness of these formulations is convenient application due to free-flowing nature and quick disintegration in water medium and applied as dilute suspensions. Size of the diluted suspended particles is very less, that is, 30–40 μm, therefore no nozzle clogging.

More advanced form of WDG is water-soluble bag-sealed WDG. In these packing bags, WDG are in partially disintegrated form, which can easily disintegrate in spray tanks (**Figure 6**).

Basic composition of WDG contains 50 to 90% pesticide (active ingredient) along with dispersing agents and wetting agents [10]. A dispersing agent is a type of surfactant that is added to formulations to improve the separation of the particles and inhibit particle size growth, and their settling or clumping. Pang et al. [11] reported lignosulfates as effective dispersing agent in water-dispersible granular formulations due to a high degree of sulfonation, high intrinsic viscosity property, and high molecular weights. Recently, sodium salt of methacrylic acid/styrene/sodium p-styrene sulfonate copolymer (SMSS) has synthesized a novel dispersant by free radical polymerization mechanism. This new dispersant has strong resistance to hard water and showed high performance and show above 90% suspensibility in hard water [12].

IPFT has developed water-dispersible granules of liquid pesticide such as triazophos. Recently, IPFT developed neem WDG for mosquito control. Other WG

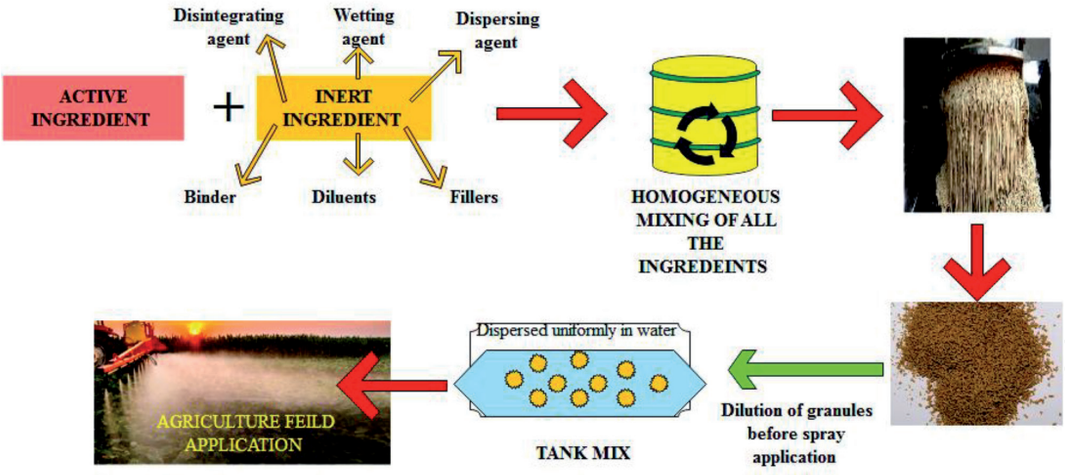

Figure 6.
Schematic representation showing key steps involved WDG formulation and its application.

formulations that have been developed by IPFT for agricultural usage are Captan 83WG, Isoproturon 75WG, Metamitron 70 WG, Mancozeb 75WG, Chlorothalonil 75WG, Endosulfan 75WG, Carbendazim 86WG, Divrinol 50WG, Thiram 80WG, Cypermethrin 40 WG, Thiamethoxam 25 WG, Deltamethrin 25 WG, and Triazophos 20 WG.

Suspension concentrate: Suspension concentrates are the stabilized dispersion of pesticides in water medium. This is the most popular formulation due to its safe and convenient use. The suspended particle size is very fine and provides good adhesion and penetration on target surface, which results in improved bio-efficacy. It has recently identified that SC formulations show less leaching of pesticides than conventional emulsifiable concentrate formulations. Similarly, another study has identified that in SC formulations, volatilization of active ingredient in environment reduced to 33.5% compared with conventional pesticide formulations [13]. Suspension concentrates have overcome the limitations associated with conventional organic solvent-based formulations (**Figure 7**).

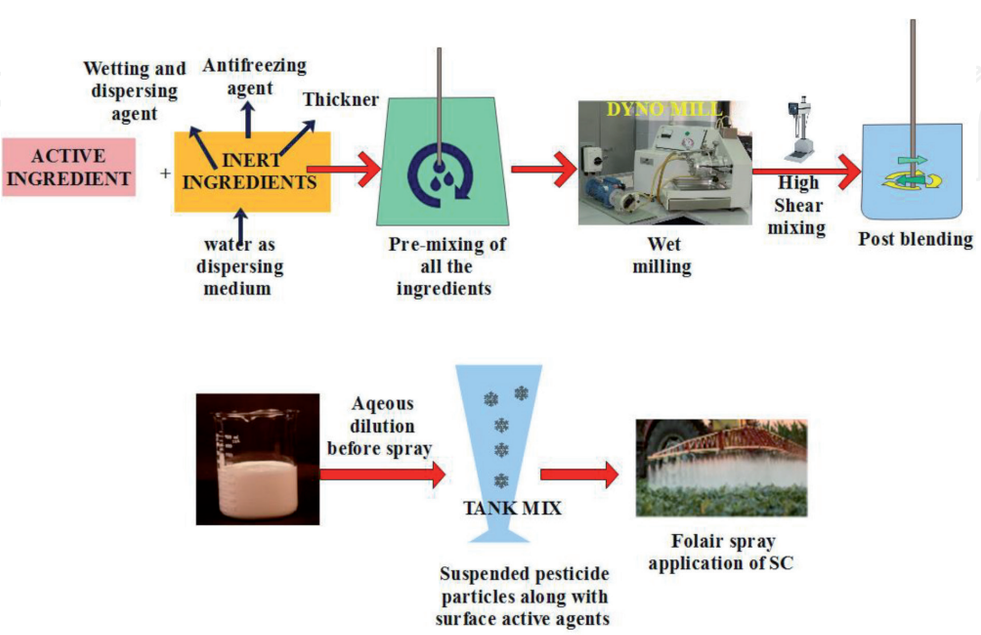

Figure 7.
Schematic key steps involved suspension concentrate formulation and its application.

The main advantages of suspension concentrates are easy application, no organic solvent used, and free from any toxicity to users and environment.

Careful selection of surfactant system is necessary to prevent hetero-flocculation (agglomeration of solid particles and droplets) during storage. There are three types of instabilities identified in SC during storage due to particle size change and they are particle aggregation, Ostwald ripening, and particle sedimentation [14].

5. Recent advances in suspension concentrate formulations

Effect of polymeric surfactant on physical stability has investigated in suspension concentrate. Polymeric surfactants provide high critical micellar concentration (CMC) and reduced Gibbs-free energy ΔG [15]. In another study, silicone surfactant is used as adjuvants in the SC formulation that results in high performance of surfactant and improves the physical stability and the quality of the formulation [16].

Particle size is also an important factor for stability as well as bio-efficacy enhancement. In a study, Vineela et al. [17] have reported that in *Bacillus thuringenesis* SC formulations, further reduction of particle size enhanced the bio-efficacy of formulation against *Spodoptera litura* (Lepidoptera: Noctuidae).

Some pesticides are photosensitive and easily decomposed. In a study, an amine-modified ligno-sulfonate surfactant was synthesized to make the SC formulation anti-photolysis [18]. Similar advancements have been conducted in IPFT on botanical-based formulations to inhibit photolysis. In addition to this, IPFT has developed several other UV protectant-based SC formulations for various SC formulations.

Entomopathogenic fungus, *Beauveria bassiana*, has been formulated as SC against *Helicoverpa armigera* larvae with LC_{50} value of 61.22 mg l^{-1} after 3 days of application [19]. Several other entomo-pathogenic fungi have been formulated as SC formulation by IPFT against various insect pests of different economically important crops such as spices and oil crops of Asian region.

Along with this IPFT has developed many synthetic and botanical pesticide SC formulations for agricultural pest control which include Isoproturon 50SC, Carbendazim 50SC, Sulfur 52SC, fipronil 5SC, thiomethxam 14.1% + Lamda cyhalothrin 10.6% SC, metamitron 70 SC, Neem SC, etc.

5.1 Capsule suspension (CS)

Capsule suspension (CS) is water-based slow release formulation containing active ingredient encapsulated inside microcapsules up to 10 microns size (**Figure 8**). CS formulation is a stable suspension of micro-capsules containing active ingredients and these microcapsules are synthesized by interfacial polymerization mechanism. CS formulations provide regulated, slow, and delayed the release of pesticides. This formulation is safer delivery mode by giving protection from toxic ingredients and stops the pesticide rate of degradation.

5.2 Advanced features of CS

CS are water-based (free from any organic solvent) homogeneous and uniform suspension formulation. Its application is safe, and provides enhanced and efficient bio-safety with reduced phytotoxicity. In order to develop CS formulation, the active ingredients should have low solubility in water and altogether hydrolytically stable. The pesticide from microcapsules gets slowly released after application. The CS formulations are slow release formulations and theses formulations prolong the availability of pesticide at target site. The CS formulation reduces environmental

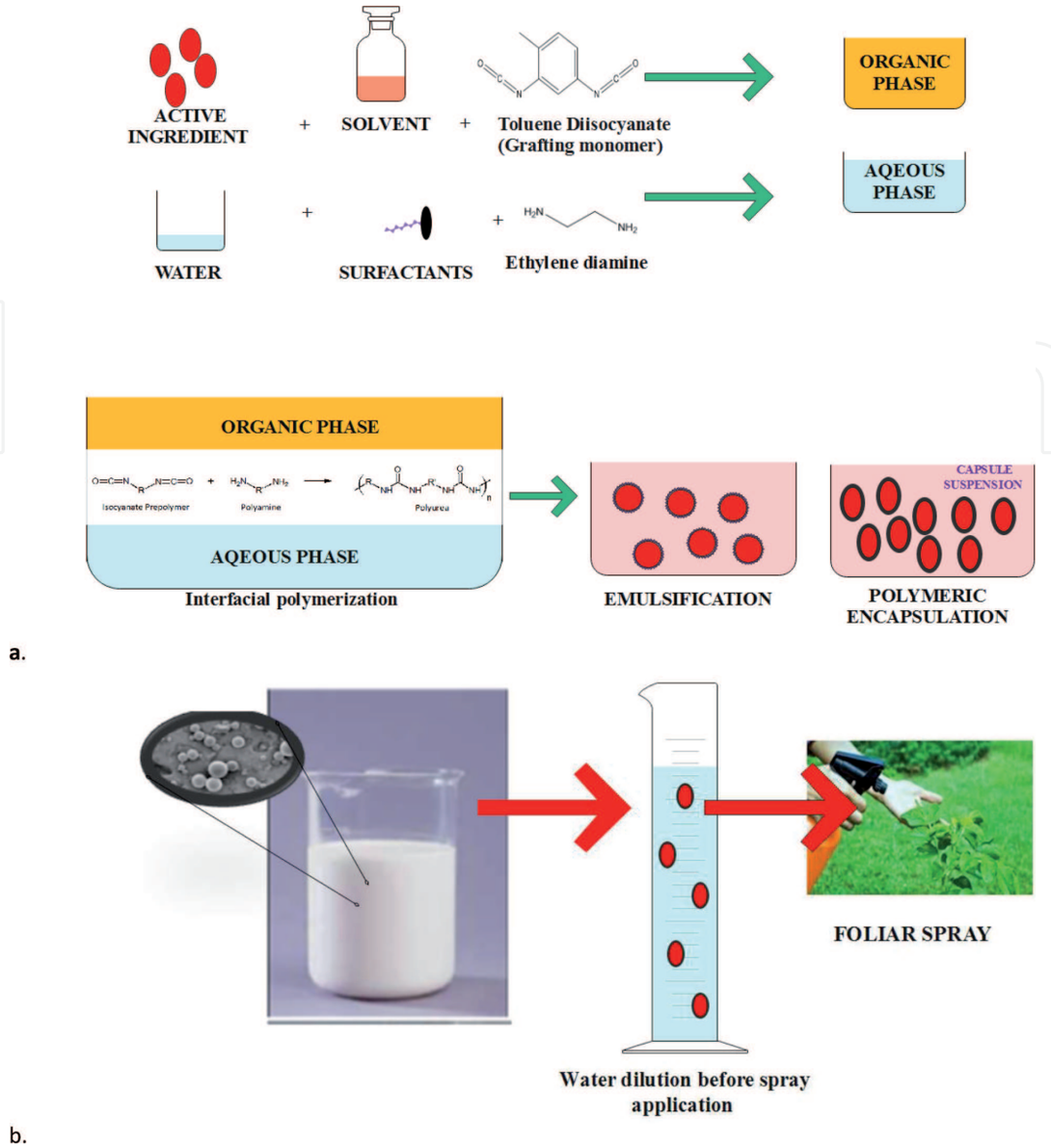

Figure 8.
Schematic representation of capsulated suspension formulation procedure a. and its application b.

contamination and leaching of pesticide and degradation of active ingredient by environmental factors like sunlight.

In a recent study, it was found that carboxy, methyl cellulose (CMC) and diallyl, dimethyl, ammonium chloride (DMDAAC) as monomers are the effective encapsulating agents of avermectin pesticide. This capsulated form gave higher performance and has excellent UV protecting property [20]. Thus, IPFT has developed CS for seed dressing for targeted delivery of pesticides without any wastage in environment [21].

Cyhalothrin is the most effective and broad-spectrum pesticide used in Central Asia. It has dual mode of action contact as well as systemic. Most efficient CS formulations developed by IPFT for sustainable agricultural applications are Lambda Cyhalothrion 10CS and Lambda Cyhalothrin 4.9CS.

5.3 Microemulsion

Microemulsion (ME) is the most efficient delivery system of botanicals as well as synthetic pesticides. By definition- "ME is a system of water, oil, and an amphiphile which is a single optically isotropic and thermodynamically stable liquid solution" [22].

Droplet size of ME is in nano-range, that is, 10 nm–20 nm. Based on dispersion medium, ME can be classified into two categories: O/W ME and W/O ME. Aqueous dilution of ME is required before spray application (**Figure 8**). Being a new-generation formulations, the characteristic features of MEs are nano sized, thermodynamically stable system with good penetrability, quick spreading ability, low and zero interfacial tension, and extended shelf life formulation.

6. Preparation methods of ME formulation

6.1 Phase inversion method

In phase dispersion method, dispersed phase is surfactant system along with active ingredient and water is the dispersant. The whole phase of inversion occurs in controlled temperature and other conditions for active kinetics (**Figure 9**).

Characteristic features of ME: ME formulation can effectively mask smell of the unpleasant active ingredients and protect pesticides from hydrolysis and oxidation. It enhances the solubility of water insoluble pesticides, regulates and slowdowns pesticide release, and increases bio-efficacy.

6.2 Use of ME in agriculture

Cyhalothrin ME was developed and found as the most promising pesticide formulation in China [23]. Carbendazim is another pesticide that was formulated as ME and its bio-efficacy was evaluated in *Rhizoctonia solani* [24]. Chlorpyriphos pesticide ME was successfully developed and found the most potent, safe, and environment-friendly pesticide formulations in comparison with conventional pesticide formulation in recent years [25].

Along with the synthetic pesticides, botanical-based microemulsions are well known in Asian agriculture. Essential oil in microemulsion form gives superior bioactivity as compared with emulsion forms [26]. In microemulsion system, spreading capacity and dispersion improves over applied plant surface. Therefore,

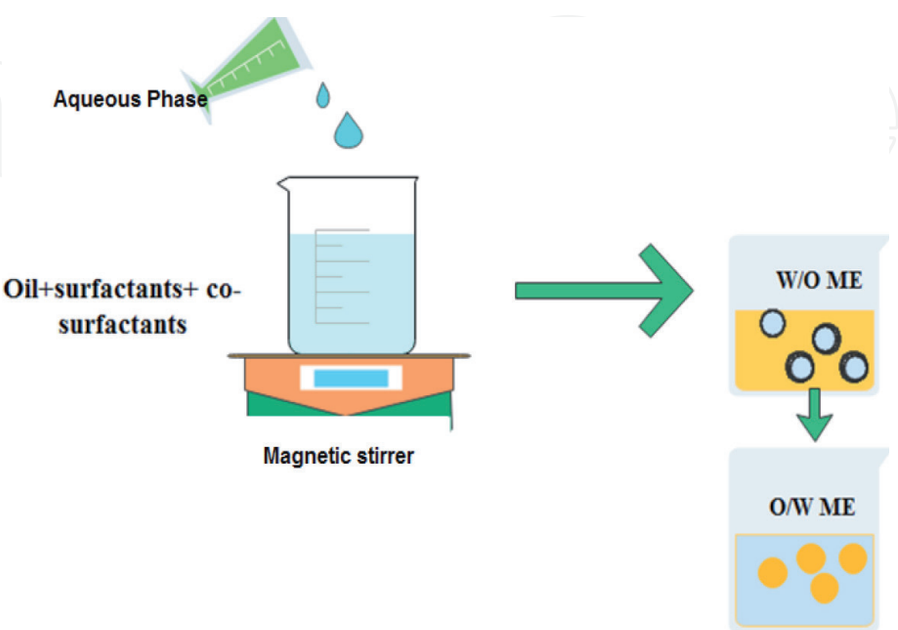

Figure 9.
Diagrammatic representation of the phase inversion method of microemulsion.

microemulsion system is the important vehicle for essential oil targeted delivery in a small quality without any losses [27, 28]. In addition, essential oil bio-constituents uniformly disperse after application over active targeted sites and offers improved bio-efficacy [29].

Clove (CO) and lemongrass oil (LGO) ME have investigated as efficient anti-fungal agents against *Fusarium oxysporum* f.sp. *lycopersici* without any phytotoxicity to main crop [30]. Previous studies in Asian region revealed that synthetic pesticide- and botanical-originated microemulsion could be an advanced, green, safe formulation against different crop pests. Therefore, microemulsion is the one of new-generation formulations for safest delivery system.

IPFT has developed different types of microemulsions of synthetic pesticides along with botanical pesticides. In addition to this, IPFT has prepared microemulsion system with inbuilt adjuvants and synergist, which will enhance the formulation efficiency and efficacy. There are different botanical-based microemulsions have been developed and formulation techniques transferred to various agrochemical industries.

6.3 Nanoemulsion formulation

Nanoemulsions are defined as nano-sized droplets dispersion in immiscible liquids (**Figure 10**). Different pesticides have been formulated as nano-formulation and researchers have quantitatively estimated the pesticide content by various characterization techniques [31]. This formulation exhibits the property of encapsulation and regulated release of pesticides for extended period of time as in controlled release formulations.

Characteristic features of nanoemulsion formulation techniques are small droplet size with low amount of surfactant and active ingredient. Similar to ME, NE can enhance solubility of active ingredient, increase bioactivity, and improve spreadability (during application). Moreover, it can reduce volatility and hydrolysis of active ingredient.

It has been evaluated that nanoemulsion formulation showed enhanced bio-efficacy results compared with emulsifiable concentrates (EC) and microemulsions (ME). This study was conducted in third-instar larva of *Plutella xylostella* [32]. Indian Agriculture Research Institute (IARI), India, has developed nano-sulfur

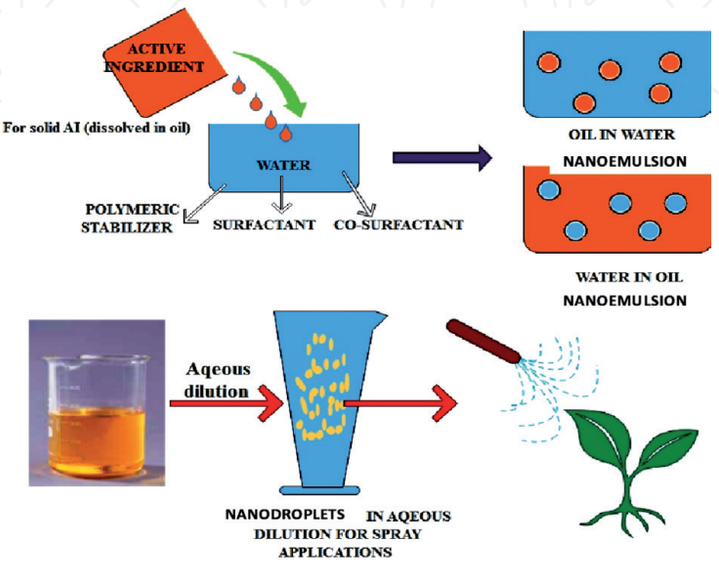

Figure 10.
Diagrammatic representation of nano-formulation preparation and its application.

formulation against *Erysiphe cichoracearum* (powdery mildew of okra) [33]. In addition to this, IARI has also developed nano-hexaconazole as effective fungicide [34]. Characteristic feature of this developed formulation is biosafety aspect, and after application of nano-hexaconazole, no impact was observed on soil nitrifiers such as blue green algae and cynobacteria species. Therefore, nano-formulations maintain the sustainable soil fertility and productivity compared with conventional formulations [35].

Many botanical-based nanoemulsions have been developed in recent years. In a study, *M. longifolia* oil nanoemulsion developed with droplet size 14 nm–36 nm. The results of study showed that in nanoemulsion formulation, its contact toxicity and durability increase. In a similar study, sea fennel (*Crithmum maritimum*) essential oil is formulated as nanoemulsion along with SiO2 nanoparticles and evaluated against *Spodoptera litura*. In other study, Eucalyptus oil NE prepared by emulsification method and insecticidal and repellent effect was evaluated against *Sitophilus oryzae*, *Rhizopertha dominica*, and *Tribolium castaneum* [36]. Nanoemulsion of *Piper aduncum* fruit extract has also been developed against cabbage pest *Crocidolomi apavonana*. Therefore, it has been concluded that botanical nanoemulsion formulation represents a new alternate for integrated pest management for organic farming promotion in Asian countries [37].

In addition to this, nanoemulsion formulation also been used as edible coating to improve the storability of fruits and vegetables in postharvest conditions for enhancing shelf life and prevention of microbial growth over fruits and vegetables [38].

IPFT has also contributed in developing many nanoemulsions of synthetic as well as bioactive pesticides and different essential oils for controlling various agriculture pests and micro-organisms. Besides this, IPFT has prepared nanoemulsion with botanical synergists and adjuvants to enhance the bioactivity and stability of nanoemulsion formulations. Moreover, combination of nanoemulsions is further developed for the amplified pest control applications in intense pest attacking conditions.

7. Emulsion in water formulation or oil in water emulsion (EW)

Emulsion in water (EW) formulation is suitable for liquid or a liquid or oily active ingredient. These formulations are dispersion of active ingredient in aqueous continuous phase (**Figure 11**). The size of the dispersed droplets ranges generally from 0.5 to 4–5 μm. EW formulations are obtained by high-shear emulsification process. Principally, EW formulations contain pesticides dispersed in the form fine liquid droplets in water and form oil-in-water (O/W) emulsions [39].

7.1 EW in agriculture

Lambda-cyhalothrin is broad-spectrum synthetic pesticide widely being used to control diamondback moth, cabbage caterpillar, cotton bollworm, and other pests that damage main food crops such as vegetables, soybeans, peanuts, and cotton [40]. This pesticide is commonly used in Asian countries due to its moderate toxicity, high insecticidal activity, and a long-lasting effect. However, lambda cyhalothrin previously available as EC and ME formulations pollutes the environment, costly due to loads of surfactants and consume non-renewable resources in the form of petroleum solvents [41]. Therefore, there is an urgent requirement to replace these shortcomings to further take the benefit of this broad-spectrum pesticide.

EW formulations such as limonene, peppermint oil, and spearmint oil have been developed and bio-efficacy evaluation was done on *Pseudococcus longispinus*.

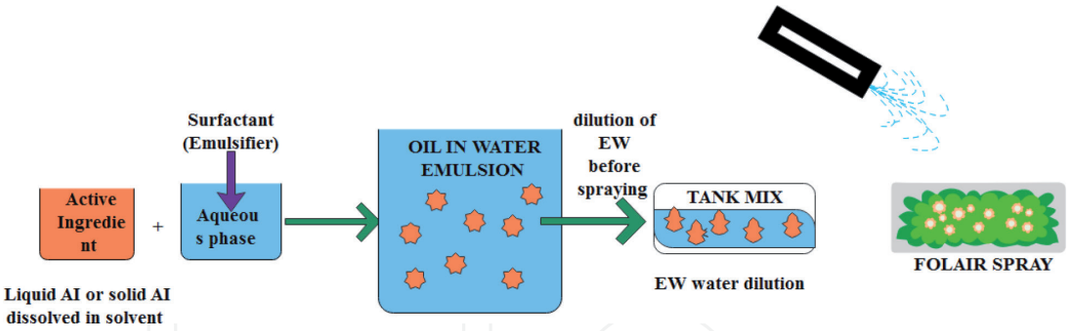

Figure 11.
Diagrammatical representation showing key steps of emulsion in water formulation and its application.

In a similar study, neem EW formulation was developed with palm oil methyl ester, RBD palm olein, and soybean oil for better adhesion and persistency. This formation was evaluated against golden apple snail. EW prepared with palm oil methyl ester showed better efficacies with LC_{50}, 45.30 mg/l under field condition and have longer persistence $t_{1/2}$ = 1.85; r^2 = 97.75 on paddy leaves [42]. The formulation was found to be very effective against the pest with 90% mortality [43]. In another study, bio-larvicide *Lagenidium giganteum* have been formulated as EW formulation. It was investigated that in EW formulation of *L. giganteum* mycelium shelf life and delivery improved for good and prolonged bio-efficacy. In a similar study, entomopathogenic fungi have been formulated as emulsion in water formulation and found to be very effective against various agricultural pests. The study concluded that EW formulation showed good bio-efficacy and stability of entomopathogenic fungi over unformulated form. Hence, emulsion in water is the safe and economical formulation against agricultural pest.

In addition to agricultural field pest control, EW formulation can also be used in preparation of postharvest packaging films with anti-insect property. Recently, cinnamon oil (CO) anti-insect packaging film has been developed for repelling *Plodia interpunctella* (Hübner) larvae [44].

IPFT has contributed to Lambda Cyhalothrin EW, Chlorpyriphos 10 EW, etc. Recently, IPFT has optimized the neem EW formulation procedure by high shear mixing. The increase in shearing intensity reduced the droplet size and resulted in higher stability.

7.2 Mixed formulations (Suspoemulsion, ZC, ZW)

The combination formulations have broad-spectrum insecticidal activities and can be applied for insect control in different Asian countries. These mixed formulations have the user and environment-friendly applications over conventional formulations.

1. ZW (Capsulated Suspension (CS) + Emulsion in water (EW)

This formulation is the combination of two formulations with two different pesticides in water medium. In this, one pesticide is encapsulated inside the polymeric coating and other is in emulsified droplet form (**Figure 12**).

IPFT has developed ZW combination formulation of capsulated suspension (CS) of Lambda cyhalothrin with concentrated emulsion in water (EW) of chlorpyriphos, and this combination was termed as ZW [7, 8]. Main advancement of this formulation is that it is the combination of two pesticides in two different formulations, one broad-spectrum pesticide, that is, in EW formulation for quick action and lambda cyhalothrin CS for controlled release and will be effective for extended

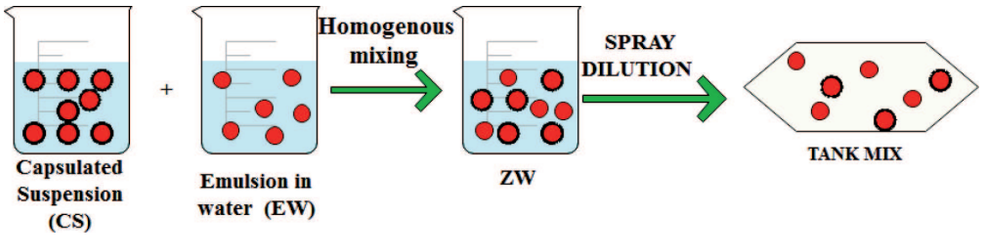

Figure 12.
Diagrammatical representation of ZC formulation and its application.

period of time and give long-term pest control [45]. This combination formulation can be used for different pesticides with good compatibility index.

2. ZC formulation (Capsulated formulation (CS) + Suspension Concentrates (SC))

The ZC formulation is the stable aqueous suspension of polymeric-encapsulated microcapsules and solid-suspended fine particles of two different pesticides. Both formulations are homogeneously mixed by wet milling and gentle shear mixing (**Figure 13**).

Chlorantraniliprole and thiamethoxam SC, lambda cyhalothrin and chlorantraniliprole ZC, thiamethoxam and lambda cyhalothrin ZC, beta-cyfluthrin and imidacloprid SC, and flubendiamide and thiacloprid SC efficacy have been evaluated against spotted pod borer. The study was found that ZC formulations gave superior results on the management of *M. vitrata* and *Spodoptera litura* over simple SC formulations [46].

In addition to enhanced bio-efficacy, this combination formulation has been investigated for non-targeted effects. ZC (thiamethoxam and lambda cyhalothrin under trade name Alika 247 bio-efficacy) was evaluated against Pest of Tea in West Bengal, India. The study reported that Alika 247 ZC was safe for the important natural predators found in the tea ecosystem relative to conventional formulations like EC [47]. Similarly, thiamethoxam and lambda cyhalothrin ZC impact was investigated on Population of Lady Bird Beetles in maize crop ecosystem in Gujarat, India [48].

This combination formulation has fast and quick knockdown and extended control of foliar insect pest. This formulation is basically developed for soybean aphids, Japanese beetle, grasshopper, corn rootworm beetle, stinkbugs, etc.

Institute of Pesticide Formulation Technology (IPFT) has developed Lambda cyhalothrin 14 CS with Diflubenzuron 10SC. The unique specialty of this developed ZC formulation is effective against early stages and adult stages simultaneously. The combined pesticide provides improved and synergistic activity. Besides this, formulation is suitable for immediate as well as for prolonged pest control practices.

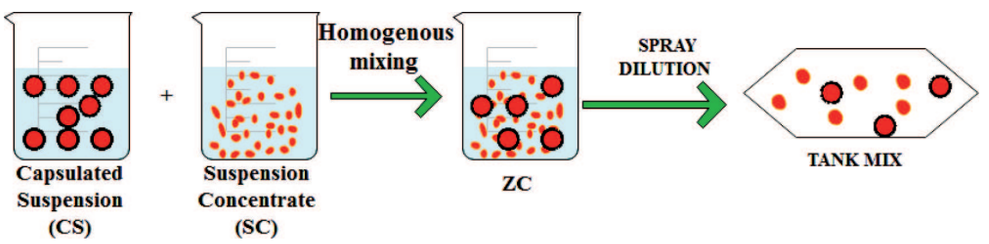

Figure 13.
Diagrammatical representation of ZC formulation and its application.

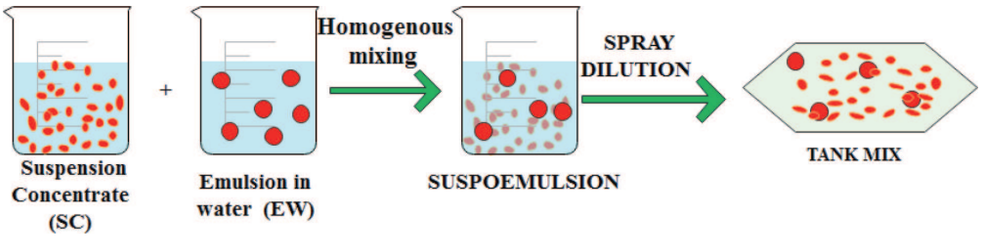

Figure 14.
Diagrammatical representation of suspoemulsion formulation and its application.

3. Suspoemulsion (Suspension concentrate (SC) + Emulsion in water (EW))

Suspension (SE) is the combination of two active ingredients one in suspension concentrate (SC) and concentrated aqueous emulsion (EW) (**Figure 14**). Suspoemulsion is the stable colloidal suspension with fine droplets with a high degree of electrostatic, steric, and hydrophobic interactions and with lesser degree of Ostwald ripening [49].

Main advancing features are different active ingredients with different solubility or melting points can be incorporated, providing broad-spectrum pest control, and tank mixing is not required. Suspoemulsions are the most convenient formulation for the farmers to apply the correct quantity of pesticides and tank mix incompatibility problems have been removed. Surfactants and thickeners were added in suspoemulsion to prevent flocculation and separation of the dispersed phases [50].

IPFT has contributed suspoemulsion of fipronil 5% SC + Soyabean oil as Adjuvant 5% EW. The main characteristic feature of this formulation is high stability and shelf life along with good bio-efficacy to agricultural pest in Asian countries.

7.3 Botanical formulations

Different bioactive phytochemicals have been identified for good bio-efficacy. These bioactive ingredients in formulated form will play a very significant role in promotion of organic farming in Asian countries in a safe and sound way. Followings botanical formulations have been formulated by IPFT.

New generation botanical-based formulations developed in IPFT, India, are as follows:

a. **Microemulsion:** *Neem oil-based microemulsions were successfully developed at IPFT, Gurgaon* [51]. *Different essential oil microemulsions have been developed by IPFT by using various botanical synergists and adjuvants.*

b. **Nanoemulsions:** Botanical origin nanoemulsions are very fine oil-in-water nano-droplet within the size of 5 nm–100 nm [52]. These nanoemulsions have both thermodynamic and kinetic stabilities [53]. IPFT has developed combined botanical nanoemulsion of eucalyptus oil with karanja and jatropha aqueous filtrates—for controlling stored grain pest *Tribolium castaneum* [54]. Uniqueness of this formulation is that karanja and jatropha aqueous extract was used from biodiesel waste product and with eucalyptus oil it gives combinatory activity. This formulation is the very efficient in terms of insect pest management and waste product management.

c. **Controlled release Formulations (CRF), microencapsulation***: This formulation technology regulates the release of pesticide and decrease the toxicity of pesticide* [55].

Highly volatile bioactive pesticides encapsulated in a thick polymeric coating by cross-linking. Therefore, these formulations are efficient for an extended period of time.

d. **Suspension concentrates:** Suspension concentrate (SC) botanical extracts have been developed by different researchers [56]. In botanical SC, botanical active ingredient is finely grinded and then dispersed in water medium with surfactants. Particle size distribution of diluted SC formulation is in the range of 2–20 μm. These formulations are eco-friendly and user friendly. Hence, botanical SC formulations are the most suitable formulation for botanicals to retain their greener characteristics.

e. **Oil dispersions (OD):** These formulations are similar to SC formulation only dispersing medium is oil in place of water as in SC. Therefore, OD formulations have good spreading and permeation compared with SC formulation. The oil dispersion formulation is the most suited formulation for hydrolytically unstable botanical pesticides. It has been reported that oil gives synergist action with botanicals and broadens the spectrum of pest management [57]. IPFT has developed oil dispersion formulations of many plant extracts against various insect pest. Recently, IPFT has developed tomato leaves extract OD formulation and found to be very efficient against mustard aphids.

Institute of Pesticide Formulation Technology (IPFT), Gurugram in India is the only institute devoted for the development of safe and environment-friendly new-generation insecticide formulation technology. There are some new formulated products of natural insecticides such as controlled release formulations, nano-formulations, or water-based formulations, which enhance the efficacy of natural pesticides against insect pest. The work carried out at IPFT greatly emphasizes on the development and promotion of environment and user-friendly pesticide formulations, also biodegradable, with the incorporation of latest technologies, and also on their commercialization.

8. Future considerations for the promotion of safe and green biopesticides

Currently, IPFT is working toward the development of safer alternatives to banned or going to be banned agrochemicals. Research is in the process of development to safer formulations with potentially low-risk user and environment-friendly novel formulation development of various broad-spectrum pesticides that are in the verge of banned have been attracting global attention. In this context, public and private sectors cooperation is necessary to facilitate the formulation development of safe and environment-friendly improved and advanced alternative. Novel formulations improve the delivery of agrochemicals and boost up the agricultural system in near future. Most important aspect along with the development is the cost of safe formulation. Maintaining low cost of novel formulations to farmers for a given product quality and availability, particularly in developing countries, is also important. Though, new formulation strategies could give out a very promising and potential option for pest control but to attain this objective, more field research is required to assess the efficacy on specific pest problems and over rising pest problems in various cropping systems. Therefore, it is a necessary requirement for strengthening the research in this safe and green formulation technology development.

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Author details

Nusrat Iqbal[1*], Amrish Agrawal[1], Md. Imteyaz Alam[2] and Jitendra Kumar[1]

1 Institute of Pesticide Formulation Technology, Gurugram, India

2 Department of Energy, Politecnico di Milano, Milan, Italy

*Address all correspondence to: nusratsiddiqa20@gmail.com

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