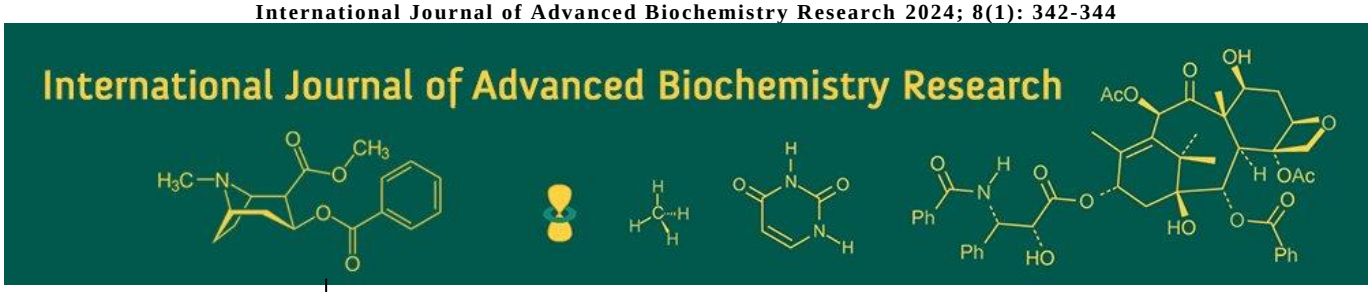

ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(1): 342-344
www.biochemjournal.com
Received: 18-10-2023
Accepted: 30-11-2023

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Rainfastness, an effective approach for insect pest management: A review

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DOI: https://doi.org/10.33545/26174693.2024.v8.i1e.375

Abstract
The rainfastness of pesticide play a significant role in the effectiveness of pesticides (which includes both active ingredient and other inert material) is affected by its formulations. Dust and wettable powder are more likely to be washed off than emulsion formulations. Fenvalerate, bifenthrin, thiamethoxam and indoxacarb reveals no significant association with rainfall and thereby show rainfastness properties as compared to phosmet with lesser rainfastness. To enhance rainfastness, incorporating additives like wax, methylated seed oil, and non-ionic surfactants can be beneficial. Moreover, the synergistic use of adjuvants such as bifenthrin + plya, *AFMNPV* + lignin/corn flours/composite and spirotetramat + adjuvants can significantly enhance rainfastness.

Keywords: Rainfastness, Adjuvants, Bt, Trichoplusiani

Introduction
Food and nutritional security are of utmost importance for the burgeoning population in the country. On an average 15-20 per cent of crop production is lost due to insects-pests, weeds, diseases, nematodes, rodents *etc*. Farmers are using pesticides as a chief tool to minimize those losses. Plant protection strategies and activities have significant importance in the overall crop production programmes for sustainable agriculture. There are many technologies for insect-pests control which include cultural, mechanical, physical, biological and transgenic plants (Gunther and Jeppson, 1960) [5], but sometime even after spraying of effective pesticides they are not getting desired control over pests due to various reasons. Among the different reasons, one of the important reason is rainfall shortly following pesticide application is an uncontrollable condition that can make pesticide use more risky for the growers and also for the general public. Effects of rainfall on pesticide wash-off are important to predict pesticide movement in the environment, integrated pest management strategies, reduce environmental pollution and develop models to predict the effect of pesticides on pest population and issue guidelines for respraying for pest control following rainfall. The amount of elapsed time between pesticide foliar application and initial rainfall can significantly affect pesticide persistence and efficacy (Willis *et al.*, 1992) [17]. Pesticide applicators mostly question if the impact of rainfastness would be seen after 10 minutes, an hour, four hours, or 24 hours after application. Hence, the context of considering these problems, an effort is made to review on rainfastness, an effective approach for insect-pest management.

Rainfastness
It is ability of pesticide to withstand against rainfall either absorbed by plant tissue or by adequately dried (Wells and Fishel, 2011) [16]. A pesticide's rainfastness, or its ability to withstand rainfall, is an important factor affecting the efficacy of foliar-applied pesticides. Generally, it is best to avoid pesticide application when rainfall is likely; however, weather is unpredictable, it is the best to choose a pesticide with good rainfastness.

Factors affecting rainfastness of pesticides
There are many factors affecting rainfastness on pesticides application like the time of rainfall occurrence after application, the amount of rainfall, the formulation of the pesticide and the properties of the targeted surface (Wells and Fishel, 2011) [16].

Effects of rainfastness on insect pest management

(a) Effect of rainfastness on insecticides

Fenvalerate showed resistance to wash-off caused higher mortality of *Helicoverpa armigera* larvae after the application of 10 mm simulated rain in tobacco (Mashaya, 1993) [7]. Pyridalyl 100 ppm found the cent per cent mortality of tobacco cutworm larvae after 7 and 14 days of simulated rainfall while, no mortality was recorded in emamectin benzoate 5 ppm in potted cabbage plants (Sakamoto *et al.*, 2005) [10]. Defoliation of leaves treated with bifenthrin, thiamethoxam and indoxacarb was not significantly affected by rainfall those of phosmet were affected in grapes (Hulbert *et al.*, 2011) [6]. While, under greenhouse condition at 12 hours after simulated rain, thiamethoxam 25 WG and sulfoxaflor 21.8 SC recorded no loss of mortality of tarnished plant bugs however, acephate 75 SP also showed zero per cent loss of mortality at 12 and 24 hours after simulated rain in cotton (Taillon *et al*., 2012) [11]. Wise *et al.* (2016)[18] reported that thiacloprid 4% F, acetamiprid 30% SG, spinetoram 25% WG and chlorantraniliprole 35% WG recorded the lowest number of live larvae of codling moth, *Cydia pomonella* on apple shoots at 0, 25.4 and 50.8 mm simulated rainfall after 24 h and 7 days treatment. The simulated rainfall at 12.7 and 25.4 mm, all insecticidal treatments except *Chromobacterium subtsugae* resulted in a significantly lower larval population compared with the untreated control. Andika *et al*. (2019) [1] noticed that without simulated rainfall, all insecticidal treatments had a significantly lower number of larvae and pupae of *Drosophila suzukii in* tart cherry. Acephate 75 SP, thiamethoxam 25 WG and sulfoxaflor 21.8 SC were found the lowest loss of mortality of tarnished plant bugs (*Lygus lineolaris*) at 0, 1, 3, 6, 12 and 24 hours after simulated rain in field condition. Spray of novaluron 8 hours after receiving rainfall resulted in equivalent mortality to spray novaluron without receiving simulated rainfall in cotton (Barrett, 2021) [2].

(b) Effect of rainfastness on insecticides with adjuvants

To improve the effectiveness of rainfastness, adjuvants also play a crucial role. The adjuvant can be defined as any additive used in conjunction with a pesticide to increase biological activity and/or to modify various physical properties of a spray solution. Adjuvant includes a surfactant, spreader, sticker, crop oil, anti-foaming material, buffering, compatibility, and deposition agents and thickeners. Adjuvants are also useful for improving the rainfastness by either be included in the formulation or added to the spray tank before application. Particularly, organosilicone surfactants are commonly used to improve rainfastness reduce surface tension and enhance spreading ability. A simulated rainfall study showed that several latex-based adjuvants improved rainfastness of chlorpyrifos, an organophosphate insecticide when it was applied in its emulsifiable concentrate formulation (Thacker and Young, 1999) [15]. The higher per cent motality of cabbage looper, *Ostrinia nubilalis* was recorded in treatment citric acid based *Bt* formulation followed by lactic acid based *Bt* formulationin after simulated rain in cotton Tamez-Guerra *et al.* (1996) [12]. Behle *et al*. (1997) [3] evaluated different *Bt* formulation against cabbage looper and found that higher per cent mortality of larvae was recorded in gluten and casein based *Bt* formulation as after simulated rain. Simulated rainfall considerably improved the retained percentage of bifenthrin + bond on the leaf surface at 0.25 and 1.0 h after treatment in test 1 in cotton. However, in test 2, bifenthrin + plyac significantly enhanced retention when rainfall occurred at 0.25 and 4 hrs. following treatment when compared to bifenthrin alone (Mulrooney and Elmore, 2000) [8]. Three *AF*MNPV formulations produced with lignin, corn flours, composite and lignin + pregelatinized corn flour (2:1) that resisted wash-off by simulated rain and provided much higher mortality of *Trichoplusia ni* neonates larvae in cotton (Tamez-guerra *et al*., 2000) [13]. The requirement for an oil-based adjuvant, such as rapeseed oil methyl - ester, in tank-mix with spirotetramat 240 SC, not only obtained a high level of control against *Aphis gossypii* under no rain conditions but also to assure good to exceptional rainfastness within 2 hours after spray treatment in cotton (Nauen *et al.*, 2008) [9]. Treatment, spinosad 5% + wax 15% and spinosad 16.7% + 15% wax significantly increased the mortality of the flies when compared to the other treatments similarly, performed significantly better than other treatments in apple (Teixeria *et al.*, 2009) [14]. The higher per cent mortality of *Drosophila suzukii* adults recorded in zeta-cypermethrin (28.2 g a.i./ha) with nu-film adjuvant after 3 and 5 days treatment at 0, 12.5, 25 and 37.5 mm simulated rainfall in blueberry (Gautam *et al.*, 2016) [4].

Conclusions

Rainfastness plays a crucial role in the effectiveness of foliar-applied pesticides for insect-pest management. Rainfall shortly following pesticide application can lead to significant wash-off, reducing the pesticide's persistence and efficacy. Factors like the time and amount of rainfall, pesticide formulation and surface properties can affect rainfastness. Fenvalerate, bifenthrin, thiamethoxam and indoxacarb reveals no significant association with rainfall and thereby show rainfastness properties as compared to phosmet with lesser rainfastness. To improve rainfastness, adjuvants can be used, such as organosilicone surfactants, which reduce surface tension and enhance spreading ability. Developing pesticides with better rainfastness and integrating adjuvants into formulations can help to minimize pest losses and ensure sustainable agriculture while reducing environmental pollution.

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