Original Article

Formulation Factors of Pyrethroid Microcapsules Affecting Rainfastness, Phytotoxicity and Mammalian Toxicity

Toshiro OHTSUBO, Hisami TAKEDA, Shigenori TSUDA
and Kozo TSUJI

*Agricultural Science Research Laboratory, Takarazuka Research Center,
Sumitomo Chemical Co., Ltd., Takatsukasa, Takarazuka 665, Japan*

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Effects of formulation factors such as mass median diameter (D) and wall thickness (T) on the rainfastness, phytotoxicity and acute mammalian toxicity of fenvalerate and fenpropathrin microcapsules were investigated. The rainfastness of fenvalerate microcapsules to cabbage was mainly regulated by T , increasing with a decrease in T . The microcapsules with T of less than *ca.* $0.05\ \mu\text{m}$ was superior to a fenvalerate emulsifiable concentrate in rainfastness. D was not a dominant factor, although the effect was not negligible. The phytotoxicity of fenvalerate microcapsules to cabbage, Chinese cabbage and cucumbers decreased with an increase in T . D was not a dominant factor, although the effect was not clear. The acute oral toxicity of fenpropathrin microcapsules in rats decreased with an increase in $D \cdot T$. It seemed to be regulated by the release rate of the active ingredient from the microcapsules.

INTRODUCTION

New types of pesticides formulations with new useful functions, *e.g.*, concentrated emulsions, suspension concentrates, dry flowables and microcapsules, have been developed in the agricultural field.¹⁻⁵⁾ At the same time, many studies have been done on microencapsulated pesticides in order to improve residual efficacy, mammalian toxicity, fish toxicity, phytotoxicity, *etc.*⁶⁻⁸⁾ Advantages of microencapsulation may be related to formulation factors such as wall material, particle size and wall thickness that regulate physico-chemical and physical properties of microcapsules.⁹⁾

In the previous study,¹⁰⁾ we investigated the efficacy of fenvalerate microcapsules against caterpillar insects and their fish toxicity. The efficacy was regulated by the parameter D/T , the ratio of mass median diameter (D) to wall

thickness (T), and the fish toxicity was regulated by $D \cdot T$, which was the product of D and T .

In the present study, we examined the effects of formulation factors (D and T) on rainfastness, phytotoxicity and acute mammalian toxicity using fenvalerate and fenpropathrin microcapsules.

MATERIALS AND METHODS

1. Microencapsulation Procedure

Fenpropathrin microcapsules were prepared by interfacial polymerization of polyisocyanate and H_2O . The wall material was polyurea.¹¹⁾ The content of fenpropathrin was 10 wt% in the final slurry. The mass median diameter (D) was controlled by changing mixing conditions when a mixture of fenpropathrin and polyisocyanate was dispersed in water containing gum arabic. Actual D was measured after preparation with a Coulter Counter

Table 1 Fenvalerate 10 wt% microcapsules.¹⁰⁾

Sample No.	Wall thickness T (μm)	Mass median diameter D (μm)	D/T
1	0.002	4.8	2400
2	0.002	31.0	15,500
3	0.005	2.0	400
4	0.011	4.8	436
5	0.011	52.0	4727
6	0.038	4.3	113
7	0.051	22.5	441
8	0.113	50.0	442

Table 2 Fenpropathrin 10 wt% microcapsules.

Sample No.	Wall thickness T (μm)	Mass median diameter D (μm)	$D \cdot T$ (μm^2)
1	0.002	4.5	0.009
2	0.004	8.8	0.035
3	0.009	8.6	0.077
4	0.010	4.9	0.049
5	0.010	19.3	0.193
6	0.020	19.8	0.396
7	0.022	10.9	0.240
8	0.041	20.3	0.832

Model TA-II (Coulter Electronics Inc.). The wall thickness (T) was controlled by changing the ratio of polyisocyanate to fenpropathrin and D . Actual T was calculated by using Eq. (1).¹²⁾

$$T = (W_w/W_c)(\rho_c/\rho_w)(D/6) \quad (1)$$

where W_w , weight of wall material; W_c , weight of core material; ρ_w , density of wall material; ρ_c , density of core material and D , mass median diameter.

The microencapsulation procedure of fenvalerate 10 wt% microcapsules was the same as described in our previous paper.¹⁰⁾

The microcapsules used in this study are summarized in Tables 1 and 2.

2. Rainfastness Test of Fenvalerate 10 wt% Microcapsules on Cabbage

The fenvalerate microcapsules shown in Table 1 and a fenvalerate 20 wt% emulsifiable concentrate were diluted to 100 ppm fenvalerate with water and sprayed on potted cabbage (Shikidori). In the case of the

Table 3 Criterion for observing phytotoxicity.

Index	Damaged area on a leaf
0	0
1	less than 5%
2	5%–30%
3	30%–60%
4	60%–80%
5	more than 80%

fenvalerate microcapsules, 200 ppm Tokusei Rino (Nihon Nohyaku Co., Ltd.) was added into the dilution as a wetting agent. Artificial rainwashing (40 mm of rain per hour) was conducted immediately after spraying and at 90 min after drying with artificial rainwashing equipment DIK-6000 (Daikirikakogyo Ltd.). After air drying, a treated leaf was cut off and ten 3rd-instar larvae of tobacco cutworm, *Spodoptera litura*, were confined to contact with the leaf in a plastic cup (12 cm i.d.). The mortality was determined after 48 hr.

3. Phytotoxicity Test of Fenvalerate 10 wt% Microcapsules

The fenvalerate microcapsules were diluted to 400 ppm fenvalerate with water containing 200 ppm Tokusei Rino as a wetting agent and sprayed on potted cabbage (Shikidori), Chinese cabbage (Muso) and cucumbers (Hokushin). Phytotoxicity was observed after 1 week using the criterion shown in Table 3, and the degree of phytotoxicity was calculated by using Eq. (2).

Index of the degree of phytotoxicity

$$= \frac{\sum(\text{index of damaged area} \times \text{number of classified leaves}) \times 100}{(\text{total number of leaves observed}) \times 5} \quad (2)$$

where index of damaged area=index in Table 3 and number of classified leaves=number of leaves classified into the corresponding index in Table 3.

4. Determination of Mammalian Toxicity of Fenpropathrin 10 wt% Microcapsules in Rats

The fenpropathrin microcapsules were orally administrated to 7 week old SD rats (CrS-CD). The acute oral LD₅₀ (mg/kg) of each

microcapsule was evaluated and compared with that of the fenpropathrin 10 wt% emulsifiable concentrate. The relative toxicity was calculated by using Eq. (3).

$$\text{Relative toxicity (\%)} = \frac{(\text{acute oral LD}_{50} \text{ of EC}) \times 100}{(\text{acute oral LD}_{50} \text{ of MC})} \quad (3)$$

where EC, fenpropathrin 10 wt% emulsifiable concentrate and MC, fenpropathrin 10 wt% microcapsule.

RESULTS AND DISCUSSION

1. Rainfastness of Fenvalerate Microcapsules on Cabbage

Figure 1 shows the relationship between D/T , the ratio of mass median diameter to wall thickness, and the mortality of *S. litura* with fenvalerate microcapsules without rainwashing. The mortality with sample No. 6 with low D/T was low, whereas the mortality with samples with D/T of more than 400 was almost 100%. Our previous paper¹⁰⁾ reported that the D/T of fenvalerate microcapsules affected the efficacy against *S. litura* and that the LC_{50} value decreased with increasing in D/T . In the present study, we reconfirmed that the efficacy of the microcapsules increased with increasing in D/T .

As shown in Table 4, the mortality was lower after rainwashing than without rain-

Fig. 1 Relationship between D/T and the mortality of *Spodoptera litura* with fenvalerate 10 wt% microcapsule without rainwashing.

No. in the figure, sample No. of fenvalerate 10 wt% microcapsule; D/T , the ratio of mass median diameter to wall thickness.

Table 4 Rainfastness of fenvalerate 10 wt% microcapsules.

Sample No.	Mortality of <i>Spodoptera litura</i> (%)		
	No rainwashing	Rainwashing immediately after spraying	Rainwashing after drying
1	98	91	94
2	98	99	96
3	98	96	86
4	98	63	95
5	99	93	91
6	29	15	—
7	74	0	14
8	99	3	6
EC ^{a)}	95	52	88

^{a)} Fenvalerate 20 wt% emulsifiable concentrate.

washing, especially with samples No. 7 and 8. The mortality did not differ much whether rainwashing was done immediately after spraying or after drying.

To clarify the relationship between formulation factors such as D and T , and rainfastness, we introduced the rainfastness factor (RF) calculated by using Eq. (4) as a parameter of rainfastness.

$$RF (\%) = (M_{rs}) / (M_{nr}) \times 100 \quad (4)$$

where M_{rs} , mortality of *S. litura* rainwashed immediately after spraying and M_{nr} , mortality of *S. litura* not rainwashed.

Figure 2 shows the relationship between D/T and RF. In the samples with D/T of around 400, RF varied in the range of 0 to 100%, which means D/T that regulated the mortality without rainwashing was not the parameter that controlled the mortality after rainwashing.

Figure 3 shows the effect of D on RF when T was constant. When T was ca. 0.01 μm , RF increased with increasing in D . When T was 0.002 μm , however, RF did not increase so remarkably. Figure 4 shows the effect of T on RF. The lower the T , the higher the RF, and the effect of D was not so significant. The RF of the microcapsule with T of more than 0.05 μm was almost zero. On the other hand, the microcapsule with T of less than ca. 0.02 μm had a higher RF than the fenvalerate

Fig. 2 Relationship between rainfastness factor (RF) and D/T of fenvalerate 10 wt% microcapsule.

No. in the figure, sample No. of fenvalerate 10 wt% microcapsule; D/T , the ratio of mass median diameter to wall thickness; RF, $(M_{rs})/(M_{nr}) \times 100$, where M_{rs} =mortality of *Spodoptera litura* with rainwashing immediately after spraying and M_{nr} =mortality of *Spodoptera litura* without rainwashing.

Fig. 3 Relationship between rainfastness factor (RF) and D of fenvalerate 10 wt% microcapsule.

No. in the figure, sample No. of fenvalerate 10 wt% microcapsule; D , mass median diameter; T , wall thickness; RF, $(M_{rs})/(M_{nr}) \times 100$, where M_{rs} =mortality of *Spodoptera litura* with rainwashing immediately after spraying and M_{nr} =mortality of *Spodoptera litura* without rainwashing.

emulsifiable concentrate (55%).

From the above discussion, it was concluded that T mainly affected the rainfastness of the microcapsule and that D was not a dominant

Fig. 4 Relationship between rainfastness factor (RF) and T of fenvalerate 10 wt% microcapsule.

T , wall thickness; RF, $(M_{rs})/(M_{nr}) \times 100$, where M_{rs} =mortality of *Spodoptera litura* with rainwashing immediately after spray and M_{nr} =mortality of *Spodoptera litura* without rainwashing; figures in (), mass median diameter.

factor although the effect of D was not negligible. It is not clear at this stage why T mainly affects RF. Since the degree of rainfastness is supposed to be affected by the binding strength between plant surface and microcapsule after spraying, research on binding strength may be required to make clear the mechanism of rainfastness of microcapsules.

2. Phytotoxicity of Fenvalerate 10 wt% Microcapsules

Figure 5 shows the degree of phytotoxicity of the fenvalerate microcapsules to cabbage, Chinese cabbage and cucumbers. The three plants did not differ much in phytotoxicity decreased with increasing in T . For example, the phytotoxicity to cucumbers was in order of No. 7 and No. 8, No. 6, No. 4, No. 3, No. 1, No. 2. The microcapsules with T of more than $0.051 \mu\text{m}$ were not phytotoxic. D was not a dominant factor to the phytotoxicity, although the relationship between phytotoxicity and D was not clear.

Generally, a pesticide becomes phytotoxic when the active ingredient is in contact with a plant. The active ingredient should be released through the wall from microcapsules to cause phytotoxicity. For releasing the active ingredient, two mechanisms have been proposed: release by diffusion through the wall and breaking of microcapsules. As for the former, it has been reported that the release rate of the active ingredient is controlled by

Fig. 5 Phytotoxicity of fenvalerate 10 wt% microcapsules.

No. in the figure, sample No. of fenvalerate 10 wt% microcapsule; D , Mass median diameter; T , wall thickness.

$D \cdot T$ and that it is inversely proportional to $D \cdot T$.¹⁰⁾ In the later case, D/T affects the strength of microcapsules and breaking of microcapsules increases with increasing in D/T .^{9,13)}

Thus, if the phytotoxicity of fenvalerate microcapsules is affected by the diffusion of fenvalerate through the wall, it decreases with decreasing in the release rate. As a result, the phytotoxicity decreases with increasing in $D \cdot T$. On the other hand, if the phytotoxicity is caused by the breaking of microcapsules, the phytotoxicity decreases with decreasing in the degree of the breaking. In this case, it decreases with decreasing in D/T . In both cases, it is expected that the phytotoxicity with the microcapsules decreases with increasing in T . This reasoning for the mechanism of phytotoxicity with microcapsules agrees with the experimental results described above. When the release by diffusion is a main mechanism, phytotoxicity decreases with increasing in D . On the contrary, when breaking is a main mechanism, it decreases with decreasing in D . Thus, if both mechanisms work at the same time, they counteract the effect of D . This may be the reason why the effect of D was almost negligible.

3. Acute Oral Toxicity of Fenpropathrin 10 wt% Microcapsules in Rats

It seems reasonable to assume that the active ingredient outside the wall is responsible for acute oral toxicity in the case of micro-encapsulated pesticides. As described above, there are two mechanisms for the release of the active ingredient from microcapsules, *i.e.*, release by diffusion through the wall and breaking of microcapsules, and $D \cdot T$ affects the former while D/T the latter.

Figure 6 shows the acute oral toxicity of

Fig. 6 Acute oral toxicity of fenpropathrin 10 wt% microcapsules in rats.

No. in the figure, sample No. of fenpropathrin 10 wt% microcapsule; $D \cdot T$, product of mass median diameter and wall thickness; relative toxicity in rats, ratio of the acute oral toxicity of fenpropathrin 10 wt% emulsifiable concentrate to that of fenpropathrin 10 wt% microcapsule.

Table 5 Formulation factors of pyrethroid microcapsules to regulate their functions.

Item	Formulation factor
Initial efficacy	D/T ^{b)}
Residual efficacy	D/T
Phytotoxicity ^{a)}	Mainly T ^{c)}
Rainfastness	Mainly T
Fish toxicity	$D \cdot T$ ^{d)}
Acute oral toxicity	$D \cdot T$

^{a)} Mass median diameter (D) is not a dominant factor.

^{b)} Mass median diameter/wall thickness.

^{c)} Wall thickness.

^{d)} Product of mass median diameter and wall thickness.

fenprothrin 10 wt% microcapsules in rats. The toxicity of the microcapsules relative to the fenprothrin 10 wt% emulsifiable concentrate decreased with increasing in $D \cdot T$.

Thus, when the microcapsules are administered orally to rats, it is supposed that the release rate of the active ingredient through the wall regulates the absorption of the active ingredient through the gastrointestinal organs.

We report the properties of pyrethroid microcapsules in the present and previous papers.¹⁰⁾ The formulation parameters of pyrethroid microcapsules to regulate the physicochemical, biological and toxicological properties are shown in Table 5.

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要 約

耐雨性、薬害およびほ乳動物毒性に影響を及ぼすピレスロイドマイクロカプセルの製剤要因

大坪敏朗, 竹田久巳, 津田重典, 辻 孝三
フェンバレレートマイクロカプセルおよびフェンプロパスリンマイクロカプセルを用い、マイクロカプセルの粒径 (D) および膜厚 (T) と耐雨性、薬害およびラットに対する急性経口毒性との関係について検討した。フェンバレレートマイクロカプセルの耐雨性は主として T により制御され、 T が小さくなるほど耐雨性が向上した。また T が約 $0.05 \mu\text{m}$ になった場合にはマイクロカプセルはフェンバレレート乳剤よりも優れた耐雨性を示した。 D の効果は無視できないもののその寄与は小さかった。フェンバレレートマイクロカプセルのキャベツ、ハクサイ、キュウリに対する薬害を調べた結果、 T が大きくなるにつれ薬害は低下した。 D の効果は明確ではないが、その影響は小さいものと判断された。フェンプロパスリンマイクロカプセルのラットに対する急性経口毒性は $D \cdot T$ 値が大きくなるほど低下した。毒性は、マイクロカプセルからの有効成分放出速度により制御されているものと推測された。