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Formulation Dependent Degradation of Cadusafos: A Comparative Study under Thermal and Photolytic Conditions

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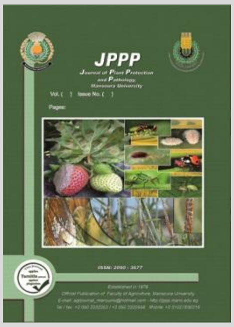

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ABSTRACT

The present paper discusses the degradation of the organophosphate pesticide cadusafos in terms of the active ingredient (a.i), Granules (GR), and Capsule Suspension (CS) formulations. The stability of these formulations in different environmental factors, such as accelerated storage, different temperatures (30 °C, 40 °C, and 50 °C), and in direct sunlight and UV radiation, was investigated, and the rate of degradation and half-lives were computed with the help of first-order kinetics. The CS formulation was the most stable to accelerated storage (54 ±2 °C for 14 days), with a loss of the active ingredient being 2.76% compared with 6.66% in the GR formulation. Thermal degradation tests revealed that the half-life of cadusafos decreased with increasing temperature, with the stability following this pattern: CS > GR > a.i., for example, the half-lives of CS, GR, and a.i., were 198 h, 177.69 h, and 169.02 h at 50 °C, respectively. The CS formulation had the lowest degradation with a half-life of 10.61 h under the sunlight, compared to GR and a.i., the half-lives were 8.24 h and 6.55 h, respectively. A similar pattern was recorded under UV radiation. Such findings reveal that the encapsulation technology on the CS formulation provides high levels of protection against thermal and photodegradation, which greatly increases the environmental stability of cadusafos. The study indicates the importance of the formulation type as a significant factor in the control of the environmental effectiveness of pesticides.

Keywords: Cadusafos, Capsule Suspension (CS), Granules (GR), photodegradation, thermal degradation.

INTRODUCTION

Pesticides play an essential role in contemporary agriculture by securing crops and guarantee food security. Organophosphates, such as cadusafos (*S,S*-di-*sec*-butyl *O*-ethyl phosphorodithioate), are also effective in controlling pests such as nematodes, although their environmental behavior is a significant issue. The stability of a pesticide and its effects on the environment depend heavily on its formulation. Cadusafos is a successful acetylcholinesterase inhibitor used to treat soil-borne nematodes. The chemical properties and the external factors affect its persistence and mobility in the environment. Organophosphate pesticides break down by hydrolysis, oxidation, and microbial metabolism, the rate of which varies according to pH, temperature, and microbial activity. (Coats, 1991). Formulations are synthesized to increase pesticide performance. GR formulations provide a slow release of the active ingredient and physical protection from antagonistic environmental factors (British Crop Production Council, 1976). CS formulations encapsulate the active ingredient in a polymer shell, providing controlled release and enhanced stability (Croda Agriculture, 2025). The stability of pesticides is profoundly affected by abiotic factors. Temperature has a strong effect on the dynamics of chemical reactions and the functionality of microbial populations, in which higher temperatures generally increase the pace of degradation (ElShafei *et al.,* 2009). The rate of degradation of cadusafos is strongly temperature dependent: at 25 °C, the half-life of cadusafos is 1056 h with a loss of only 14.6%, at 35 °C, the half-life of cadusafos is 472.5 h with a loss of 29.7%, and at 45 °C, it is 395.4 h with a loss of 34.3%. These findings illustrate that increased temperature quickens volatilization and degradation of cadusafos by chemical reactions, reducing its environmental half-life (Eissa *et al.,* 2006). Cadusafos is reported to photodegrade, but the rate can differ with the media (e.g., soil, water) and the sunlight intensity and spectrum (FAO, 2010). Sunlight (and, in particular, ultraviolet light) triggers photodegradation, and its rate depends on the environment and the intensity of light (FAO, 2010; Makram *et al.,* 2020). Cadusafos photodegradation is rapid, with a half-life of 5.79 hours and a 74.3 percent loss after exposure to natural sunlight. An initial loss reaches 29.7% within 2 h and 51.2% in 6 h, which means that molecular excitation caused by sunlight is faster than UV radiation, and the protection properties of various formulations against UV are of great interest. The degradation of cadusafos is possible by UV rays, and the half-life depends on the particular UV light range and the environment (Eissa *et al.,* 2006). Granular and capsule formulations change the immediate availability of the active ingredients to water, light and microbes; this typically slows surface photolysis and may alter bioavailability to degrading microbes, but the magnitude and direction depend on formulation design and matrix (Fenner *et al.,* 2013).

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This study aims to evaluate the degradation kinetics of cadusafos, both as an active ingredient (a.i.) and in formulations as Granules (GR) and Capsule Suspension (CS), at different environmental conditions such as temperature, sunlight, and ultraviolet (UV) radiation. Cadusafos was identified and confirmed by gas chromatography (GC) with an external standard. The present research aims to find the most stable formulation of cadusafos under certain environmental conditions. It conducted a rigorous comparison between stability and degradation pathways of the three formulations. The results are targeted to gain valuable knowledge for optimal application and environmental mitigation.

MATERIALS AND METHODS

Chemicals

Cadusafos PESTANAL®, an analytical standard used in this study, was purchased from the Supelco® company. It has a CAS registry number of [95465-99-9], a molecular weight of 270.4, a molecular formula of $C_{10}H_{23}O_2PS_2$, and a purity of 98%. Two formulations of cadusafos used in this investigation, Rugby® 10% GR (w/w) and Rugby® 20% CS (w/v), were manufactured by FMC – Mexico and locally supplied by Dalta Company. The methanol used in this work was high-performance liquid chromatography for analysis grade purchased from Merck. The chemical structure of cadusafos is described in Fig. 1 as follows:

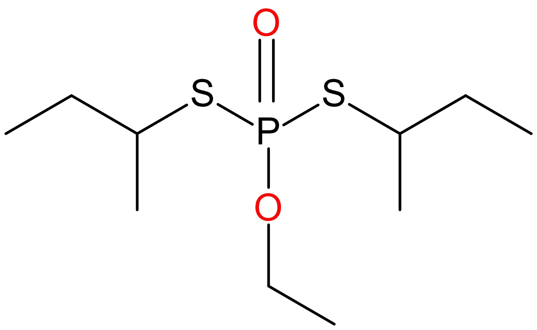

Fig. 1. Chemical structure of cadusafos

Accelerated storage procedures:

Capsule Suspension (CS).

Storage stability was carried out according to the methods CIPAC MT 46 (1995) and CIPAC MT 46.1.3 (1995). The cadusafos 20% CS formulation was dispensed into bottles with a volume of approximately 50 ml. The bottles were securely sealed and subjected to a temperature of 54 ±2 °C in an oven for a duration of 14 days. Upon reaching the designated time, the bottle was extracted from the oven, the cap was removed, and both the bottles and their contents were subsequently allowed to undergo natural cooling until they reached room temperature. The cap was then replaced once the cooling process was complete. The samples of CS formulation were collected at different periods of 0, 3, 7, and 14 days.

Granules (GR).

The cadusafos 10% GR formulation was evenly distributed by placing approximately 20 g into separate beakers. The disc was placed onto the surface of the granules within the beaker, where it rests with a loose fit. The dimensions of the disc are such that it can apply a pressure of 25 g/cm^2 to the sample's surface within the beaker. Subsequently, the beakers were subjected to a temperature of 54 ±2 °C for a duration of 14 days within the confines of an oven (MT 46.1.7 (1995)). Samples of GR formulation were collected at different periods of 0, 3, 7, and 14 days.

Preparation of samples:

Cadusafos after accelerated storage at 54 ±2 °C:

Standard Preparation

A cadusafos analytical standard of known purity was weighed into a 25 ml grade (A) measuring flask, dissolved, and completed with methanol.

Sample Preparation

A specific weight equivalent to 10 mg of cadusafos analytical standard was taken from each formulation, transferred to a 25 ml grade (A) measuring flask, and completed with methanol. The concentration was then determined using GC-FID.

Impact of varying temperatures, direct sunlight, UV radiation exposure, and extraction methods.

A stock solution (400 µg ml^{-1}) of standard cadusafos and cadusafos formulations was prepared and dissolved in methanol. The active ingredient is 400 µg ml^{-1} in one milliliter of methanol. Afterward, 1 ml of stock solution was collected and spread as uniformly as possible in uncovered Petri dishes (5 cm i.d.) and was left to dry at room temperature when subjected to the different treatments at successive periods.

The Petri dishes were divided into three groups. The first group was exposed to sunlight, while the second group was exposed to short UV-rays at 254 nm at 12 cm. Samples were collected from the first and second groups at 0,1,2,4,6,8,10,12, and 24 hours of exposure. The third group was exposed to different temperature degrees (30, 40, and 50 ^{o}C) for 0,1,3,6,12,24,48,96,144,168,336 and 672 hours inside a dark electric oven with a temperature regulating system. Residues in Petri dishes were quantitatively transferred to known volumes with methanol and then determined using GC-FID (Kandil *et al.,* 2011).

Measurements

1. GC Determination

An Agilent 7890B gas chromatograph paired with an autosampler 7693 was utilized in the procedure, which had set the Flame Ionization Detector (FID) at 250 °C and used a 30 m x 0.53 mm I.D. x 1 µm film thickness capillary column HP-50+. The nitrogen carrier gas was constantly pumped at 8 ml/min. After waiting at a set column temperature of 200 °C for one minute, the temperature was ramped to 260 °C at a rate of 20 °C/min. 250 °C is the set temperature for the injector, which was in splitless mode. A one-microliter sample was used for the injection. Under these conditions, cadusafos had a retention time of 2.529 minutes. The standard for cadusafos is illustrated in Fig. 2. The active standard exhibited outstanding linearity in the range of 4-400 ng µl^{-1} with a correlation coefficient of 0.99991, as shown in Fig. 3.

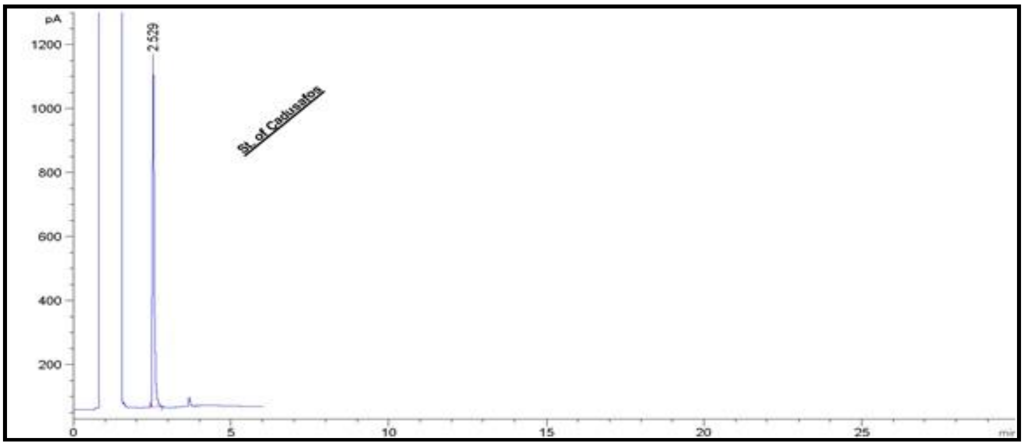

Fig. 2. Chromatogram of cadusafos Standard

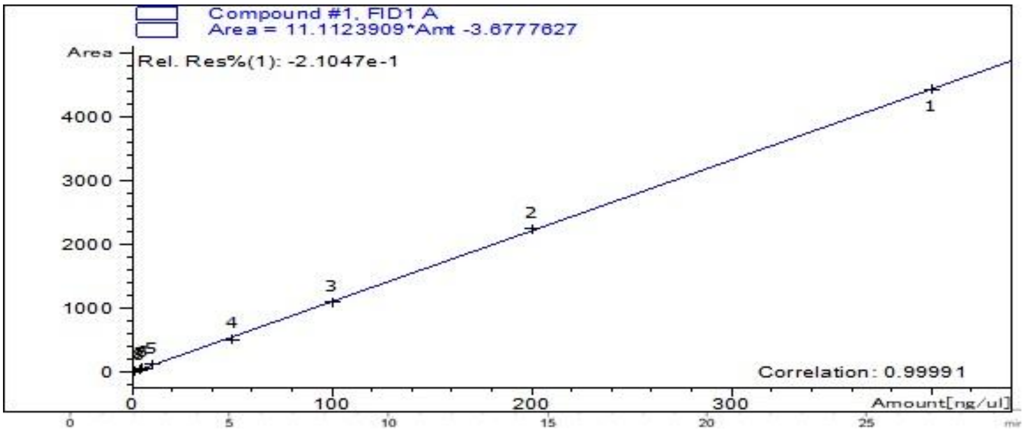

Fig. 3. Standard calibration curve of cadusafos using GC-FID

2. Kinetic study

(El-Dars *et al.,* 2023; Ismail & Seloma 2025) observe that the concentration decrease of most of the studied pesticides is a first-order kinetics. In this way, we can find the half-life of cadusafos using the correct first-order kinetics equation. We used the following first-order rate equation to determine the rate constant of the degradation and the half-lives.

$$C_t = C_0e^{-kt}$$

C_t is the pesticide concentration at time t, C_0 is the initial concentration, and k is the degradation rate constant in (hours^{-1}). The k value was determined from plotting concentration logarithm against time while the half-life time $t_{0.5}$ was derived using the relationship:

$$t_{0.5} = Ln\ (0.5)/k$$

3. Statistical analysis

The results for all experiments were determined in triplicate and expressed as the mean ± Standard Deviation (SD). The reaction of the degradation kinetics was studied by a first-order model. Linear regression was performed to plot the natural logarithm of concentration (Ln C) vs. time in Microsoft Excel. The slope of the regression line directly provided the degradation rate constant (k), and the coefficient of determination (R^2) was estimated to assess the linearity and the accuracy of the kinetic model to the experimental data.

RESULTS AND DISCUSSION

Effect of accelerated storage on cadusafos formulations

The stability of cadusafos in its Granules (GR) and Capsule Suspension (CS) formulations was tested at 54 ±2 °C with accelerated storage over a period of 14 days. The findings are shown in Table 1, which revealed that CS formulation was more stable as compared to the GR formulation. The CS formulation (20% w/v) had a low loss of 2.76% of the active ingredient after 14 days of storage. The GR formulation (10% w/w) on the other hand showed a stronger degradation with a loss of 6.66% after the same duration. These findings suggest that there is a high thermal stability of the CS formulation, and the GR formulation is stable when stored acceleratedly. This indicates that the protective barrier that the encapsulation in the CS formulation offers is what retards the degradation of cadusafos during high-temperature storage.

Table 1. Effect of accelerated storage on the content of cadusafos formulations at 54 ±2 °C for 14 days.

Storage Periods (Days)	CS		GR	
	cadusafos content 20% (w/v)	Loss %	cadusafos content 10% (w/w)	Loss %
0*	19.95 ±0.67**	0	9.91 ±0.31	0
3	19.90 ±0.51	0.25	9.85 ±0.26	0.61
7	19.75 ±0.60	1	9.60 ±0.41	3.13
14	19.40 ±0.32	2.76	9.25 ±0.18	6.66

*** Samples before and after the accelerated storage stability test were analyzed together to reduce the analytical error.**

**** Each value represents an average of three replicates: FAO tolerance ±6% for CS and ±10% for GR formulations: mean or average and STDEV.**

Effect of temperature on the degradation of cadusafos formulations

The thermal degradation experiments on the cadusafos active ingredient (a.i.), GR formulation, and CS formulation at three temperatures, namely, 30 °C, 40 °C and 50 °C, showed that cadusafos had considerable temperature-dependent degradation patterns in all the formulations. The findings indicate that the process of cadusafos degradation demonstrates first-order kinetics, which is shown by the stable correlation between temperature and half-life numbers.

Effect of temperature at 30 °C on the degradation rate of cadusafos formulations.

The loss of cadusafos and its half-life ($t_{0.5}$) degradation data are presented in Table 2 and Fig. 4. The effect of temperature at 30 °C on the degradation rate of a.i., and two commercial cadusafos formulations is presented. Degradation of cadusafos in all three formulations was relatively slow. At the end of 672 hours, the percentage loss was 50.92 % for the a.i., 47.42 % for the GR formulation, and 47 % for the CS formulation. Their half-lives were 630 hours for the a.i., 693 hours for the GR formulation, and 770 hours for the CS formulation, which shows the CS formulation at this temperature is the most stable.

Table 2. Effect of temperature at 30 °C on the degradation rate of cadusafos formulations.

Times (hours)	30 °C					
	a.i		CS		GR	
	µg**	% loss	µg	% loss	µg	% loss
0*	400 ±1	0	400 ±1	0	400 ±1	0
1	399.6 ±0.48	0.1	399.7 ±0.36	0.08	399.5 ±0.62	0.12
3	398.3 ±0.94	0.42	398.8 ±1.33	0.3	398.2 ±0.95	0.45
6	396.1 ±1.33	0.97	397.8 ±0.90	0.55	397.43 ±1.27	0.64
12	392.6 ±1.02	1.85	395.8 ±0.77	1.05	394.53 ±1.09	1.37
24	386.5 ±0.88	3.38	391.2 ±0.78	2.2	388.56 ±1.17	2.86
48	375 ±1.10	6.25	382.5 ±0.83	4.38	379.9 ±0.28	5.03
96	355.7 ±1.03	11.08	366 ±0.45	8.5	361.11 ±0.51	9.72
144	340.1 ±1.06	14.97	349.8 ±0.60	12.55	346.33 ±0.73	13.42
168	331.9 ±0.70	17.03	342.7 ±0.36	14.32	337.96 ±0.74	15.51
336	280.2 ±0.83	29.95	292.5 ±0.95	26.88	285.66 ±1.16	28.58
672	196.3 ±0.56	50.92	212 ±0.35	47	210.33 ±1.14	47.42
$t_{0.5}$ (hours)	630		770		693	

*: Samples were collected directly after the quantitative transfer (zero time).
: Each value represents an average of three replicates: mean or average and STDEV. $t_{0.5}$*: Half-life value

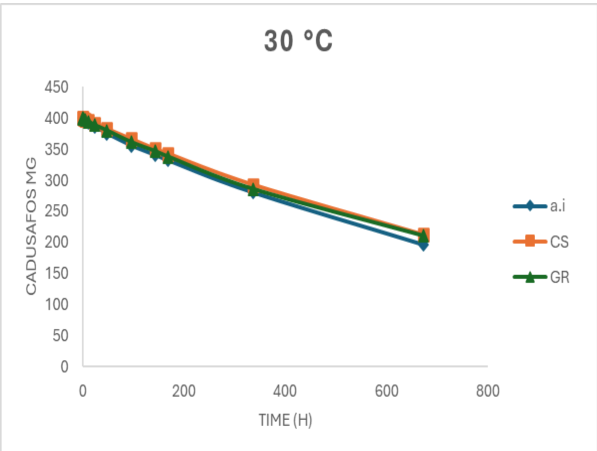

Fig. 4. Effect of temperature at 30°C on the degradation rate of cadusafos formulations.

Effect of temperature at 40 °C on the degradation rate of cadusafos formulations.

The impact of temperature at 40°C on the degradation rate of the active ingredient (a.i.), and the two commercial cadusafos formulations is presented in Table 3 and Fig. 5. All samples exhibited an increased degradation rate at 40 °C. After 672 hours, the loss percentages were 72.65%, 70.62% and 68.68% for the a.i., GR and CS formulations, respectively. The respective half-lives calculated were 364.74 hours for a.i., 385 hours for GR, and 407.65 hours for CS. Once again, the CS formulation was the most stable.

Table 3. Effect of temperature at 40 °C on the degradation rate of cadusafos formulations.

Times (hours)	40 °C					
	a.i		CS		GR	
	µg**	% loss	µg	% loss	µg	% loss
0*	400 ±1	0	400 ±1	0	400 ±1	0
1	399.01 ±0.57	0.25	399.4 ±0.78	0.15	399.11 ±0.41	0.22
3	396.5 ±0.72	0.88	398.3 ±0.94	0.42	397.4 ±0.25	0.65
6	395.5 ±0.64	1.12	396.1 ±0.68	0.97	397.8 ±0.90	0.55
12	390.4 ±0.36	2.4	393.9 ±0.57	1.53	392.1 ±0.88	1.97
24	380.3 ±0.86	4.92	382.8 ±0.53	4.3	381.9 ±0.74	4.53
48	354.3 ±0.95	11.42	367.7 ±0.52	8.08	365.8 ±0.78	8.55
96	332.8 ±0.54	16.8	339.1 ±0.50	15.22	333.7 ±0.72	16.58
144	303 ±0.80	24.25	309.3 ±0.77	22.67	308.5 ±0.53	22.88
168	289.3 ±1.07	27.68	299.8 ±0.67	25.05	291.2 ±0.91	27.2
336	209.5 ±0.45	47.62	224.7 ±1.16	43.82	216.3 ±1.03	45.92
672	109.4 ±0.43	72.65	125.3 ±0.56	68.68	117.5 ±1.02	70.62
$t_{0.5}$ (hours)	364.74		407.65		385	

*: Samples were collected directly after the quantitative transfer (zero time).
: Each value represents an average of three replicates: mean or average and STDEV. $t_{0.5}$*: Half-life value

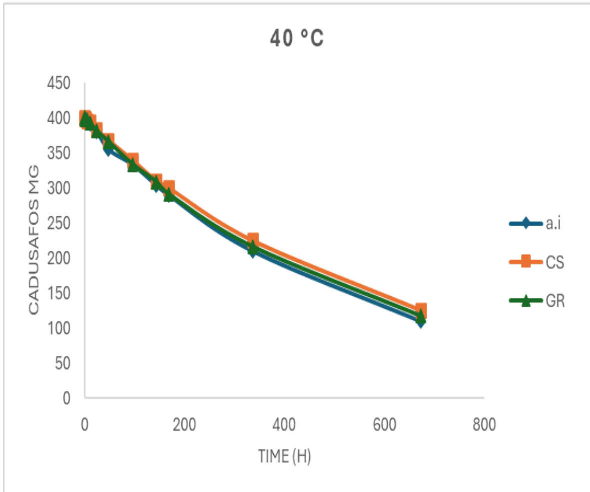

Fig. 5. Effect of temperature at 40°C on the degradation rate of cadusafos formulations.

Effect of temperature at 50 °C on the degradation rate of cadusafos formulations.

Table 4 and Fig. 6 represent the influence of temperature at 50 °C on the rate of degradation of a.i., and the two commercial formulations of cadusafos. The process was even faster at 50 °C. In 672 hours, the a.i., the GR and the CS formulation had lost 93.64 %, 92.80 % and 90.84 %, respectively.

The half-lives were significantly decreased to 169.02 hours for the a.i., 177.69 hours for the GR formulation and 198 hours for the CS formulation. In line with the findings at lower temperatures, the CS formulation was the most stable at higher temperatures.

Table 4. Effect of temperature at 50 °C on the degradation rate of cadusafos formulations.

Times (hours)	50 °C					
	a.i		CS		GR	
	µg**	% loss	µg	% loss	µg	% loss
0*	400±1	0	400±1	0	400±1	0
1	398.7±0.73	0.33	399.1±0.43	0.22	398.5±0.89	0.38
3	393.9±0.50	1.53	396±0.45	1	395.3±1.03	1.17
6	389.1±0.96	2.72	392.2±1.18	1.95	391.3±1.07	2.17
12	380.4±1.01	4.9	384.1±0.45	3.97	380.2±0.47	4.95
24	362.2±0.78	9.45	367±0.29	8.25	365.8±0.81	8.55
48	328.4±0.91	17.9	337.9±0.74	15.53	330.6±0.67	17.35
96	268.7±0.72	32.83	285.4±1.13	28.65	276.6±0.84	30.85
144	221.6±0.46	44.6	247.2±0.92	38.2	232.8±0.50	41.8
168	199.7±0.68	50.08	220.56±0.77	44.86	211.6±0.74	47.1
336	106.1±0.94	73.47	123.1±0.43	69.22	112.7±1.13	71.82
672	25.42±0.73	93.64	36.65±0.72	90.84	28.8±0.79	92.8
$t_{0.5}$ (hours)	169.02		198		177.69	

***: Samples were collected directly after the quantitative transfer (zero time).**
****: Each value represents an average of three replicates: mean or average and STDEV. $t_{0.5}$***: Half-life value**

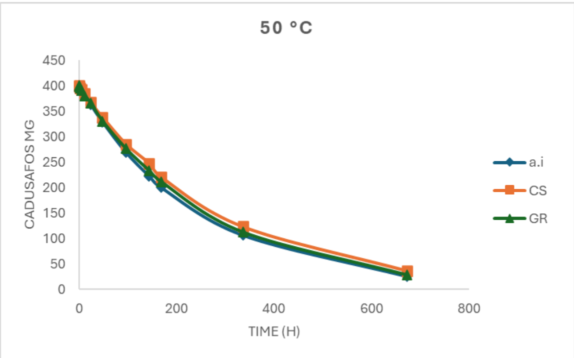

Fig. 6. Effect of temperature at 50°C on the degradation rate of cadusafos formulations.

Effect of direct sunlight exposure on the degradation rate of cadusafos formulations.

Table 5 and Fig. 7 help to show how the rate of degradation of a.i., and the two tested commercial cadusafos is influenced by exposure to direct sunlight. The degradation of all formulations was time dependent as the quantity of the active ingredient (a.i.) reduced throughout the 24 hours of observation. The percentage loss of CS, GR, and a.i., was 6.35%, 7.7% and 10.53% at the 1-hour mark, respectively. After 24 hours, all formulations were found to be highly degraded. CS formulation had a loss of 78.8%, GR a loss of 86.4% and the a.i., had the most significant loss of 91.84%.

Table 5. Effect of direct sunlight on the degradation rate of cadusafos formulations.

Times (hours)	a.i		CS		GR	
	µg**	% loss	µg	% loss	µg	% loss
0*	400±1	0	400±1	0	400±1	0
1	357.9±1.07	10.53	374.6±0.80	6.35	369.2±0.97	7.7
2	322.3±0.91	19.42	349.2±0.95	12.7	341.1±0.81	14.72
4	261.9±0.45	34.53	307.7±0.61	23.08	288±1.03	28
6	211.9±0.57	47.02	268.8±0.69	32.8	242.1±0.56	39.48
8	181.4±0.97	54.65	236.4±1.11	40.9	206.5±0.75	48.38
10	129.1±1.14	67.72	207.3±0.95	48.18	173.2±0.99	56.7
12	101.5±0.98	74.62	171.4±1.13	57.15	136.5±0.94	65.88
24	32.65±0.45	91.84	84.8±0.50	78.8	54.4±0.64	86.4
$t_{0.5}$ (hours)	6.55		10.61		8.24	

***: Samples were collected directly after the quantitative transfer (zero time).**
****: Each value represents an average of three replicates: mean or average and STDEV. $t_{0.5}$***: Half-life value**

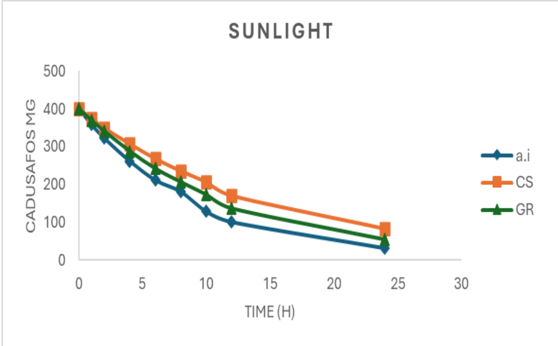

Fig. 7. Effect of direct sunlight on the degradation rate of cadusafos formulations.

The half-life ($t_{0.5}$) values in direct sunlight were 10.61 hours with CS, 8.24 hours with GR, and 6.55 hours with the a.i.,. These values show that the CS formulation exhibited the lowest rate of degradation, followed by GR, followed by the a.i., which degrades fastest under direct sunlight.

Effect of short UV rays (245 nm) on the degradation rate of cadusafos formulations.

Table 6 and Fig. 8 provide the profiles of the degradation of cadusafos under short UV rays (245 nm). Just like when exposed to direct sunlight, all the formulations deteriorated with time. The percentage loss in CS, GR, and a.i., after 1 hour was 4.72%, 6.8%, and 7.5 %, respectively. The CS formulation demonstrated a 73.03% loss, GR demonstrated an 80.68% loss, and the a.i., showed an 84.86% loss after 24 hours.

Table 6. Effect of short UV rays (245nm) on the degradation rate of cadusafos formulations.

Times (hours)	a.i		CS		GR	
	µg**	% loss	µg	% loss	µg	% loss
0*	400±1	0	400±1	0	400±1	0
1	370±0.77	7.5	381.1±0.58	4.72	372.8±0.71	6.8
2	341.8±0.56	14.55	358.33±0.87	10.42	348.21±0.94	12.95
4	293.1±1.11	26.72	321.4±0.89	19.65	303.7±0.59	24.08
6	250.65±0.91	37.34	286.8±1.00	28.3	265.2±1.13	33.7
8	205.8±0.81	48.55	258.11±0.88	35.47	231.42±0.96	42.14
10	182.6±0.68	54.35	233.9±0.74	41.52	204.7±0.86	48.82
12	153.46±1.04	61.64	209.9±0.56	47.52	172.7±0.72	56.82
24	60.55±0.49	84.86	107.9±0.60	73.03	77.3±0.82	80.68
$t_{0.5}$ (hours)	8.78		12.72		10.11	

***: Samples were collected directly after the quantitative transfer (zero time).**
****: Each value represents an average of three replicates: mean or average and STDEV. $t_{0.5}$***: Half-life value**

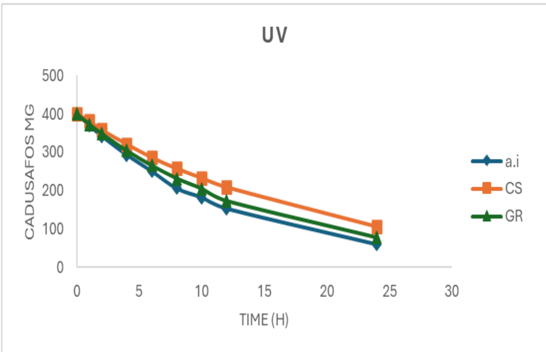

Fig. 8. Effect of short UV rays (245nm) on the degradation rate of cadusafos formulations.

Under the effect of short UV rays, the half-life ($t_{0.5}$) of CS, GR, and the a.i., was 12.72 hours, 10.11 hours, and 8.78 hours, respectively. These findings once again reveal that the CS formulation provided the best protection against degradation, followed by GR, with the a.i., degrading most rapidly under short UV radiation.

This study gives a detailed analysis of the degradation dynamics of cadusafos, as a.i., and in its GR and CS formulations under different environmental stressors. The obtained results demonstrate the high stability of the CS formulation on a regular basis, and this finding has far-reaching consequences for the efficacy, application, and environmental fate of this nematicide.

The study of the effects of temperature on the breakdown of cadusafos demonstrated that there was, as expected, an increase in the rate of breakdown with increasing temperatures. This is also consistent with the principles of chemical kinetics. There was an inverse relationship in the rate of degradation, as well as in the half-lives of the three forms. The CS formulation, at the temperature of 30°C exhibited the longest half-life of 770 hours, 40°C exhibited 407.65 hours, and 50°C exhibited 198 hours. This is consistent with the notion that the microcapsule polymeric shell is a substantial microscale thermal insulator, the rate of hydrolysis or thermally induced rearrangement reactions which are moderated insulation are reaction rates are dominated. These are consistent with (Croda Agriculture, 2025) which stated that the polymer shell in CS formulation controlled release, and increase stability. The GR formulation, in comparison with the pure a.i., provided some acceptable level of protection. However, it was still noticeably less efficient than the CS formulation. This is probably due to the fact that the granular matrix is more porous, and as a result, provides less of a barrier to heat transfer.

A close match with the works of (Eissa *et al.,* 2006) emerged with the result of temperature dependent degradation of cadusafos, with half-life values of 1056.18 h at 25 °C, 472.54 h at 35 °C, and 395.36 h at 45 °C. The differences in the values can be explained by the fact that the experiment conditions slightly vary, yet the general tendency is similar.

The study showed that photocatalytic degradation was much more aggressive than thermal degradation. While thermal studies showed hundreds of hours of degradation, cadusafos under sunlight and UV radiation was degraded within hours. This shows that cadusafos is persistent in the environment and under the studied conditions. As always, the CS formulation was the most persistent, with half-lives under sunlight of 10.61 hours and UV light of 12.72 hours. This 'protective effect' is likely due to the capsule material, which contains UV light absorbing compounds, or the refractive index scatters much of the incident radiation and protects the active ingredients that are photosensitive. Some protection from the GR formulation is also evident, with half-lives in direct sunlight and short UV of 8.24 hours and 10.11 hours, which is between CS and the pure a.i. This suggests that the GR's granular structure creates a light barrier. As expected, the unprotected a.i. was the most degradable to photocatalytic degradation. Photodegradation is one of the degradation pathway of cadusafos (FAO, 2010), also, (Eissa *et al.*, 2006), with a half-life of 5.79 hours and 7.33 hours under direct sunlight and UV radiation, reported quickly photocatalytic degrading cadusafos, also these observations closely reflect the results of the current analysis (6.55 hours and 8.78 hours, respectively), thus reinforcing the proven high photosensitivity of cadusafos and the noted protective effect of the CS formulation. Our results also concur with (Fenner *et al.,* 2013), who noted that granular and capsule formulations might include materials that encapsulate the photolysis reaction.

A comparative study of the formulations highlights the technological benefits of the Capsule Suspension. The encapsulation mechanism helps to provide a physical wall that keeps the active ingredient in physical isolation from the catalysts present in the environment like heat, moisture, and UV radiations. This controlled-release system not only increases the stability of the product, but it can also be useful in increasing the efficiency with which the product can be used since the active ingredient is made available in the target zone over a longer period of time. GR formulation improves the active ingredient of cadusafos. Nevertheless, it lacks the same level of protection as the CS formulation, resulting in a rapid decrease in the active ingredient concentration. These findings are important in terms of the environment and agriculture. The high stability of the CS formulation would mean that the efficacy will last a long time in the field, and the rate of introduction of pesticides into the environment would be reduced. By choosing the most stable formulation to use at a specific set of environmental conditions, growers are able to optimize their pest control and reduce their waste and off-target effects, especially in high temperature and sunlight regions. The study offers a quantitative point of reference when making informed choices of the selection and management of cadusafos formulations based on how to optimize the agricultural objectives and encourage environmental responsibilities.

CONCLUSION

The overall assessment of the degradation dynamics of cadusafos at three formulations under the varied environmental factors will offer useful information on the optimization of the pesticide application techniques and reduction in the ecological footprint. The Capsule Suspension (CS) formulation was always steadfastly stable as compared to the Granules (GR) formulation and the pure active ingredient under all the conditions tested. The temperature-dependent degradation study showed that the CS formulation had the longest half-lives at all the temperatures studied, with outstanding performance recorded at 30 °C (770 hours) in comparison with the active ingredient (630 hours). The improved thermal stability would imply that polymeric encapsulation is effective in protecting the active ingredient against any thermal-induced degradation reactions.

Under photodegradation conditions, the most aggressive degradation pathway, the CS formulation again provided the best protection. The half-lives under direct sunlight (10.61 hours) and UV radiation at 245 nm (12.72 hours) were significantly longer than those of the other formulations. This indicates that the capsule material does attenuate harmful radiation. These findings have immense practical value in regard to agriculture. The CS formulation is less susceptible to photodegradation than other formulations. Thus, it is likely to retain effectiveness under field conditions for prolonged periods, which would decrease the number of applications made and the total pesticide load to the environment. This is especially critical in hotter areas of the world with high direct sunlight, where many conventional formulations degrade rapidly and do not control pests. This increases the environmental burden for pesticide use, especially where the need for low cadusafos use is a priority. In this regard, the CS formulation offers greater environmental stewardship. It is likely to provide effective pest control while minimizing the need for repeated applications that usually result in the environmental burden of cadusafos.

Research in the future ought to work upon field validation of these laboratory results and study the precise techniques through which the capsule material shields against environmental pressures. Also, any research that focuses on the controlled release properties of the CS formulation when applied in the field would be useful in terms of optimization of application timing and dosage rates.

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تحطم الكادوسافوس اعتمادًا على نوع المستحضر: دراسة مقارنة في ظل ظروف حرارية وضوئية

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الملخص

تتناول هذه الورقة تحطم مبيد الآفات الفوسفاتي العضوي كادوسافوس من خلال المادة الفعالة (a.i) ومستحضرات حبيبات (GR) والكبسولات المعلقة (CS) . تمت دراسة ثبات هذه المستحضرات تحت عوامل بيئية مختلفة، مثل التخزين المعجل، ودرجات حرارة مختلفة (٣٠ درجة مئوية، ٤٠ درجة مئوية، و٥٠ درجة مئوية)، وفي ضوء الشمس المباشر والأشعة فوق البنفسجية، وتم حساب معدل التحطم ونصف العمر باستخدام حركيات من الدرجة الأولى. كانت صورة المستحضر CS هى الأكثر استقرارًا في التخزين المعجل (٥٤ ±٢ درجة مئوية لمدة ١٤ يومًا)، مع فقدان المادة الفعالة بنسبة ٢,٧٦٪ مقارنة بـ ٦,٦٦٪ في مستحضر GR . أظهرت اختبارات التحطم الحراري أن نصف عمر الكادوسافوس انخفض مع انخفاض درجة الحرارة، مع استقرار يتبع النمط التالي: CS > GR > a.i ؛ على سبيل المثال، كان نصف عمر CS و GR و a.i. هو ١٩٨ ساعة و ١٧٧,٦٩ ساعة و ١٦٩,٠٢ ساعة عند ٥٠ درجة مئوية على التوالي. كانت صورة المستحضر CS هي الأقل تحللاً مع نصف عمر يبلغ ١٠,٦١ ساعة تحت أشعة الشمس، مقارنةً بـ GR و a.i. ، حيث كان نصف العمر ٨,٢٤ ساعة و ٦,٥٥ ساعة على التوالى. وسُجل نمط مماثل تحت الأشعة فوق البنفسجية. وتكشف هذه النتائج أن تقنية التغليف في مستحضر CS توفر مستويات عالية من الحماية ضد التحطم الحرارى والضوئى، مما يزيد بشكل كبير من الاستقرار البيئى للكادوسافوس . تشير هذه الدراسة إلى أهمية نوع المستحضر كعامل مهم فى التحكم في فعالية المبيدات على البيئة.