THE EFFECT OF WATER AVAILABILITY, RELATIVE HUMIDITY AND PHYSICAL PROPERTIES OF SILICA DUST ON ITS EFFICACY AS A CONTROL AGENT FOR *BLATTELLA GERMANICA* (DICTYOPTERA: BLATTILLIDAE) (L.)

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Abstract—Silica dusts with different physical properties were tested against the German cockroach *Blattella germanica*. The dusts varied in their effects on cockroach mortality according to their physical properties. Oil adsorption, pore volume and surface area were the most important characteristics while particle size showed no significant effect. The rank order of decreasing toxicity was Dri-die, Gasil 23D, Gasil 114, Gasil EBN, Gasil HP25, a silica gel S4 and Gasil 200DF. When silica was applied as a suspension in water the exposure time was found to have a greater influence on efficacy than the concentration used. A 72 hour exposure at 3g/litre gave 100% mortality whereas exposure for 1 hr on 100g/litre caused only 33% mortality. Exposure of male and female cockroaches to silica dust Gasil 23D reduced the time the cockroaches were able to survive without water from 5 and 12 days respectively to 3 and 4 days, and to only 1 and 2 days in the presence of the silica dust, Dri-die. The KD_{50}s and LD_{50}s for a range of silica dusts were determined at different humidities. Humidities of up to 60% did not significantly affect the knock-down or mortality of cockroaches for the unfluorinated silica Gasil 23D and fluorinated silica Dri-die, but when humidity was increased to more than 70% it reduced efficacy of the dusts, particularly Gasil 23D.

INTRODUCTION

The rapidly increasing problem of insecticide resistance in disease vectors, such as cockroaches (Berns, 1987; Micks, 1960), combined with the high costs of developing and registering new control agents has made the reformulation of available chemicals an economically viable option. Silica dusts used for the control of cockroaches fall into this category. Their ability to kill insects by promoting abnormal rates of water loss has long been recognised (Chiu, 1939; Kalmus, 1944; Beament, 1945; Wigglesworth, 1948; David & Gardiner, 1950) and although they have the advantages of low hazard, chemical and physical stability, and a low probability of resistance development (Ebeling, 1971), they have the disadvantage that they can be repellent to insects when used in excess and can be difficult to apply and hence require technicians to be carefully trained in their application (Caruba, 1988). Work on *Sitophilus granarius* and *Oryzaephilus surinamensis* suggests that reformulation of dusts as water suspensions can surmount the problems of application (Maceljski & Korunic, 1974) although results were inconclusive suggesting efficacy may be dependent on the substrate to which they are applied (Gower & Le Patourel, 1984). The repellancy of silica dust can also mean that insufficient dust is picked up to cause mortality, or to cause knock down and prevent the insect reaching a supply of water with which to rehydrate. If these problems can be overcome through reformulation then silica dusts may provide a useful and viable alternative to conventional chemical insecticides for the control of cockroaches.

The work reported here investigates the intrinsic toxicity of a range of silica dusts in relation to their physical properties, formulation (dust or suspension) and the interaction between the efficacy of silica dust, water availability, and relative humidity.

MATERIALS AND METHODS

Determination of the intrinsic toxicity

Six different silica dusts were compared with silica insecticide Dri-die (Agrevo Corporation, U.S.A.) to evaluate relative toxicity (Table 1).

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Table 1. The physical properties of some silica dust according to the manufacturer

Dust	Oil absorption g/100 g	Surface area m^2/g	Particle size μm	Pore volume ml/g
Silica gel*	—	—	10–40	—
Silica 200DF**	80	750	4.4–5.4	0.4
Crosfield HP25**	160	400	4.5–7	1
Gasil 114**	200	320	6–8.2	1.2
Gasil EBN**	200	320	8–9.8	1.2
Gasil 23D**	290	290	5.5–7.5	1.6
Dri-die***	300	300	3	—

Manufacturers U.K.
*=MERCK LTD
**=Crossfield
***=Roussel Uclaf U.S.A.

Three week old male German cockroaches were isolated and anaesthetised with carbon dioxide. Ten insects were placed on a plastic tile (15×15 cm) (Armstrong self adhesive floor tiles, Armstrong World Industries Ltd. UK), under an inverted plastic dish (12.5 cm diameter) lightly coated with fluon (polytetrafluoroethylene). Another plastic tile treated by dusting with silica dust (a circular area 12.5 cm diameter) was placed adjacent to the tile containing the cockroaches. After two hours acclimation the insects were transferred to the treated surface by moving the inverted plastic dish from the untreated to the treated tile without dragging the dish across the surface and disturbing the dust. After one hour of continuous exposure, the process was reversed and the insects were transferred back to the untreated tile. Insect mortality was recorded at 24 and 48 hours later. No food or water were made available to the insects.

Five to eight concentrations of each type of dust, resulting in zero to 100 percent mortality were used. Three replicates, each of 10 insects, and a control (clean tiles) were used for each concentration.

The tests were conducted at a temperature of 28±1°C and a relative humidity of 45–50%. The LC_{50} and LC_{95} values were estimated for each dust by probit analysis (Finney, 1963).

Effect of silica suspension in water

The results of the LC_{50} experiments indicated that the silica dust Gasil 23D and Dri-die were the most toxic to the cockroaches, hence these were used in the subsequent experiments. Concentrations of silica suspension (20, 40, 60, 80 and 100 g/litre) were applied to the plastic tile (15×15 cm) with a 550ml proprietory household "hand-gun" sprayer until the point of runoff (3 ml). The following dosages were applied (0.266, 0.533, 0.8, 1.0, 1.33 mg/cm^2) and were left for 48 hours to dry.

In a discontinuous exposure test ten male, three week old cockroaches were anaesthetized with carbon dioxide and placed on a plastic tile under an inverted plastic dish (12.5 cm diameter) lightly coated with fluon. After two hours acclimation the cockroaches were transferred (as above) to the treated plastic tile. After one hour they were transferred back to the untreated surfaces. Insect mortality was recorded after 24 and 48 hours. There were three replicates and a control (a tile sprayed with water which was allowed to dry) for each concentration.

In the continuous exposure test the above methods were used except that the insects were confined on the dust deposit (0.0133, 0.04, 0.06, 0.133, 0.266 mg/cm^2) for 24, 48 and 72 hours, and mortality was recorded after each period.

The temperature was maintained at 27±1°C and relative humidity 45–50%. The percentage of mortality was analyzed by analysis of variance using an arcsine transformation for each concentration.

To determine the effect of formulating the dust as a suspension in water on silica dust toxicity, different concentrations of silica suspension providing between 0 to 100% mortality were applied topically to a batch of ten adult male, three week old German cockroaches, confined inside a plastic petri dish 9 cm diameter in a manner so that all insects could be within the spray range. 2.5 ml of the mixture solution was sprayed using a 550 ml proprietory household hand-gun sprayer. Each treatment was replicated 3 times in addition to a control which was sprayed with 2.5 ml water only. The following dosages were applied 0.785, 0.982, 1.178, 1.571, 1.964, 2.646 g/m^2 for Gasil 23D and 0.491, 0.589, 0.785, 1.178, 1.571, 1.964, 2.16 g/m^2 for the silica dust Dri-die. One hour after application the insects were transferred to a plastic tank (25×13×8 cm). Temperature in the tanks was maintained at 27±1°C with a relative humidity of 45–50%. No food or water was provided during the experimental period. Mortality was recorded after 48 hours. The data were analysed with probit analysis.

The efficacy of silica dust in relation to water availability

An area (120×240×15 cm) was constructed from melamine (non-porous surface) and the inside walls painted with fluon. The bottom of the arena was marked with permanent black marker into equal distances thirty centimetres each. The arena was placed in a room 3×4 m with a 12:12 h light dark regime. A reversed daylight regime with a scotophase from 0800–2000 h was used. The temperature and relative humidity were maintained at 28±1°C and 45–50%, respectively. Cockroach harbourages, consisting of rolls of corrugated cardboard (after Cornwell, 1976), were placed at one end of the arena along with 10 g of food (S.D.S. Rat and Mouse No. 1 Modified maintenance Diet, supplied by Wm. Lillico & Son Limited) placed in small petridishes (1 cm high and 2.5 cm diameter) and a supply of water (a plastic pot (5 ml) stuffed with cotton wool and soaked with water) was placed at the opposite end of the arena. Fifty male and fifty female cockroaches were added to the arena and mortality was recorded every 24 hours for two weeks. This experiment was replicated three times and considered as a control.

To test the effect of water on the mortality of cockroaches treated with silica dust the following series of experiments was carried out: (i) natural mortality in absence of water, (ii) the efficacy of silica dust in the absence of water, (iii) the efficacy of silica dust in the presence of water and (iv) the determination of the critical period for water deprivation following pickup of silica.

(i) natural mortality in absence of water: Fifty, three week old male and fifty female cockroaches the same age were released into the arena and were provided with cardboard harbourages and food (as above) but no water. Mortality was recorded every 24 hours until all the insects had died.

(ii) efficacy of silica dust in the absence of water: Fifty three week old male and fifty female cockroaches the same age were confined to one end of the arena with a plastic ring (30×10×15 cm) lightly coated with fluon. Harbourages, food and water were made available within the ring and the insects were left for three days to acclimate and to condition the harbourage. The ring and water source were then removed and the harbourages relocated to the opposite end of the arena. The cockroaches then had to walk through a 30 cm section, in the middle of the arena, dusted with Gasil 23D or Dri-die silica dusts at the recommended dose (5 g/m^2) to access the harbourage. Insect mortality was recorded every 24 hours until all the insects had died.

(iii) the efficacy of silica dust in the presence of water: An experiment was conducted as above, except that the source of water source (plastic pots 5 ml stuffed with cotton wool and soaked with water) was placed at the opposite end of the arena to the food and harbourages. Insect mortality was recorded every 24 hours for two weeks.

(iv) determination of the critical period for water deprivation following pickup of silica: Ten adult males were treated with silica dust by being confined on plastic tiles (see determination of intrinsic toxicity) for 5 minutes. Three different concentrations (0.5, 1.0 and 5.0 g/m^2) of sorptive silica dust (Dri-die) were used. The treated insects were then transferred to plastic tanks (10×5×5 cm). For each replicate (10 insects) food was provided immediately after transference and water was given at 0, 1, 5, 10, 24 and 48 hours. There were three replicates for each treatment and one control.

Mortality was recorded 48 hours after transfer to the plastic tanks.

Determination of the effect of relative humidity on the efficacy of silica dust

To determine the effects of humidity on the efficacy of the unfluorinated silica Gasil 23D and the fluorinated silica Dri-die, the humidity was varied in a large dissicator by using a sulphuric acid saturated solution (Buxton and Mellanby, 1934). The stock solution was prepared by mixing equal volumes of water and acid with further dilution made after the stock solution had cooled. Appropriate concentrations of the solution were made in a glass dish (6 cm diameter×5 cm high) and then placed in the bottom of a large dessicator. 200 mg of silica dust was distributed with a fine paint brush onto a filter paper inside a plastic dish (12.5 cm in diameter) which was placed in the dessicator for 48 hrs at 28°C over the saturated solution to equilibrate. Ten male cockroaches were then lightly anaesthestized with CO_2 and carefully placed on to the dust. The time required for knock-down and mortality was recorded. There were three replicates with a control (no silica dust) at each specific relative humidity. The data were analysed using probit analysis the KD_{50} and LT_{50} values calculated.

RESULTS

Determination of intrinsic toxicity

The intrinsic toxicity of the dusts tested was expressed in terms of the LC_{50} (Fig. 1). The LC_{50} at 48 hrs values indicated that Dri-die and Gasil 23D were the most toxic of all the compounds tested, with values of 0.324 and 0.350 g/m^2, respectively. The rank order of decreasing toxicity was Dri-die, Gasil 23D, Gasil 114, Gasil EBN, Gasil HP25, silica gel S3 (10–40 μm) and Gasil 200 DF. The S4 (40–63 μm) and S5 (70–140 μm) dusts produced no toxic effects at the highest dose applied (10 g/m^2), hence both compounds were omitted from the LC_{50} data analysis.

A multiple regression of LC_{50} values against the physical properties of the dusts indicated (Table 2) that each of the physical attributes tested had a significant effect on the size of the LD_{50}s, with the exception of particle size. Oil adsorption and pore volume negatively correlated with the LC_{50}s where surface area was positively correlated. Oil adsorption was also positively correlated

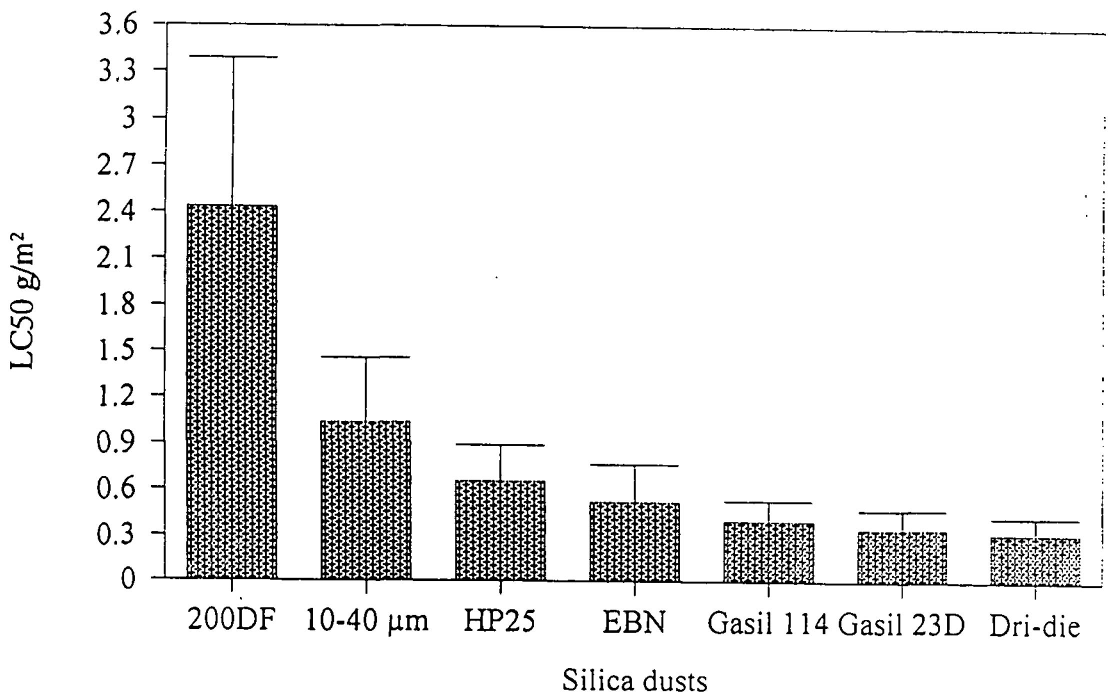

Figure 1. The intrinsic toxicity of different silica dusts assessed in term of LC_{50} values. Error bars indicate 95% confidence limits.

Table 2. Multiple regression analysis of LC_{50} values on four physical properties of seven different silica dusts tested

LC_{50}	Constant intercept	Oil adsorption	t-value	Surface area	t-value	Particle size	t-value	Pore volume	t-value	R^2
Y1	0.466	−0.008	2.925*	—	—	—	—	—	—	0.611
Y2	−1.034	—	—	0.005	20.48*	—	—	—	—	0.99
Y3	0.743	—	—	—	—	0.009	0.209ns	—	—	0.008
Y4	2.728	—	—	—	—	—	—	−1.664	38.6**	0.77
Y5	−1.23	0.0005	0.564ns	0.004	10.436*	—	—	—	—	0.98
Y6	−1.116	—	—	0.004	18.73**	0.012	0.623ns	—	—	0.98
Y7	3.539	−0.009	−3.632*	—	—	−0.147	−1.492ns	—	—	0.817
Y8	2.739	0.027	4.028ns	—	—	0.028	0.652ns	-6.568	5.450*	−0.971
Y9	−2.369	0.002	7.489*	0.005	35.60**	0.056	7.571*	—	—	0.99
Y10	−2.846	0.001	0.048ns	0.006	7.545ns	0.058	6.386ns	0.656	0.668ns	0.99

ns = not significant

* = 0.01 < P < 0.05

** = P < 0.01

with pore volume (R2=0.985, d.f.=3, 33, P<0.05). The high positive correlation of surface area with LC_{50} value caused a change of sign in the multiple regression and affected the level of significance which may explain the lack of significance of the particle coefficients in the analysis.

Effect of silica suspension in water

The result of the efficacy of silica dust suspension applied to the plastic tile is shown in Fig. 2 & 3. When exposed to the deposit for 60 minutes the increase in silica dust concentration from 20 g/litre to 100 mg/litre increased the mortality by 33% at 48 hrs. However, the lower concentration of 3 g/litre gave 100% mortality when the cockroaches were continuously confined on the treated surfaces for 72 hours. 100% mortality was also achieved after 48 hours of continuous exposure,

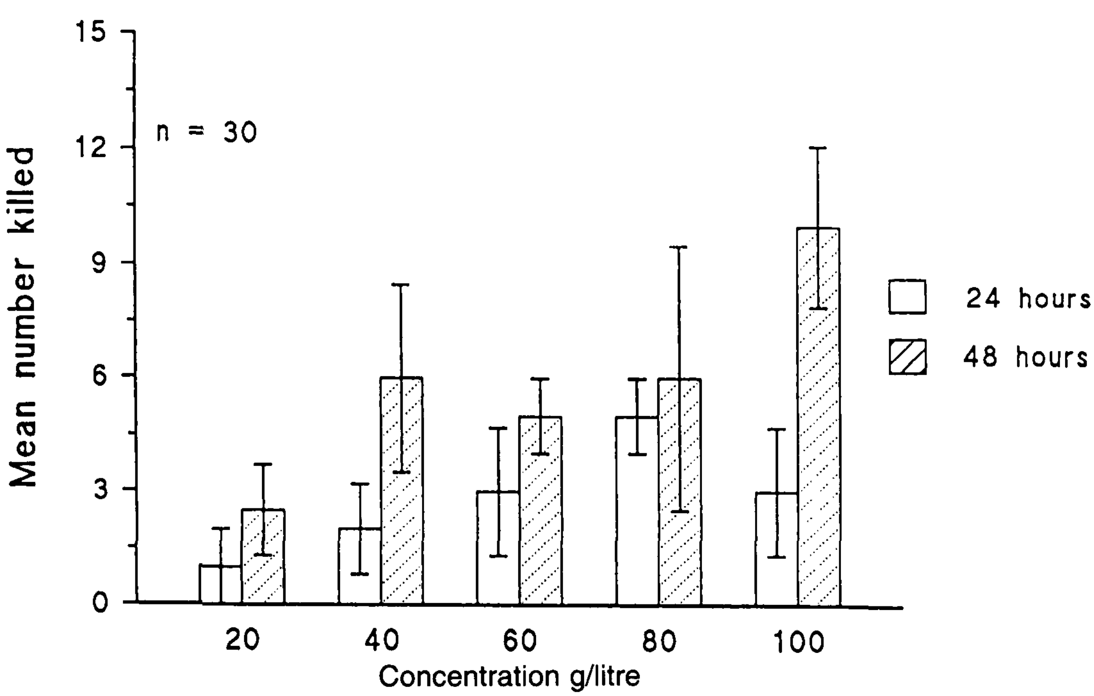

Figure 2. The effect of silica dust suspension concentration on survival of adult male German cockroaches. Error bars indicate 95% confidence limits.

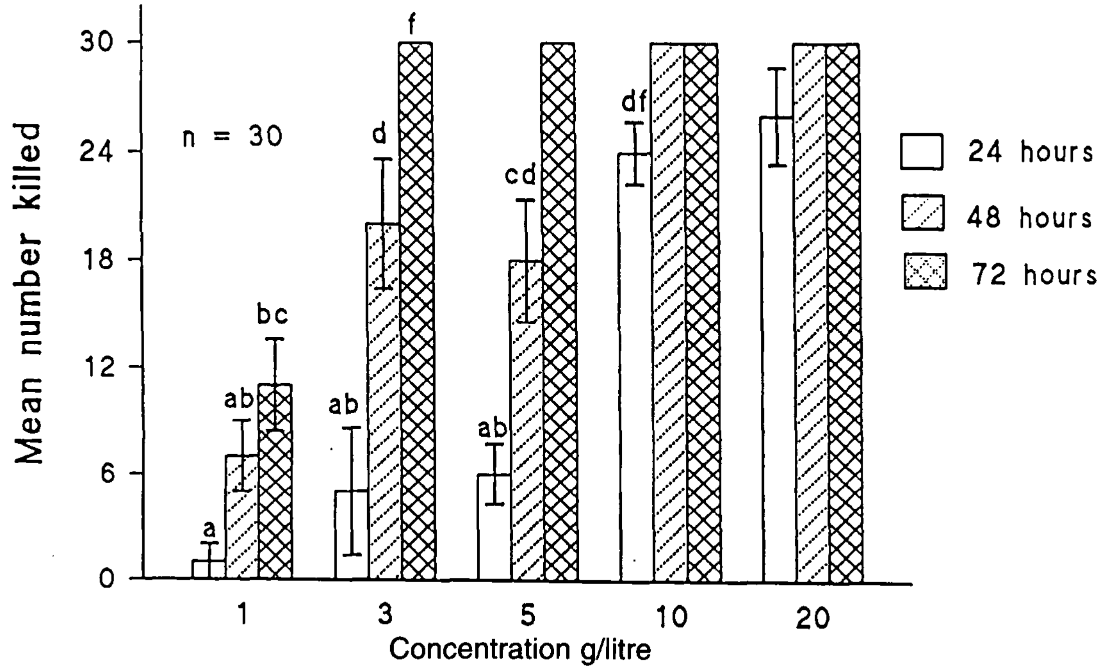

Figure 3. The effect of exposure time on the efficacy of silica dust suspension on the survival of adult male German cockroaches. Histograms carrying the same letters are not significantly different ($P>0.05$) by LSD test.

when the concentration of silica dust was 10 g/litre or more. Increasing the concentration to 20 g/litre did not significantly influence mortality in comparison with 10 g/litre after 24 hours of continuous exposure ($F=1.76$, d.f.=5, 12; $P<0.05$). The direct spray experiment clearly indicated that there was no significant difference between the application of silica in the form of dust or a topical suspension spray application (Fig. 4).

The efficacy of silica dusts in relation to water availability

The results obtained for the effects of water on mortality and efficacy of dust are shown in Figs. 5, 6 and 7. Water availability proved to be a very important limiting factor in German cockroach survival (Fig. 5). 100% mortality occurred after 5 days in males and after 12 days in females in the absence of water, compared with a mortality that did not exceed 10% of the population in the control, where water was readily available. Figures 5 and 6 indicate the effect of water availability on cockroach mortality when exposed to an area dusted with silica dust (Dri-die or Gasil 23D). 100% mortality was achieved in less than 4 and 5 days, for males and females respectively in the absence of water. When water was available the mortality after two weeks was only 42% in males and 12% in females, in the case of Gasil 23D, but reached levels of more than 85% with Dri-die. Hence, the efficacy of the Gasil 23 silica is greatly reduced when adequate supplies of water are available to the cockroaches.

The time elapsed between the pick-up of the dust and finding a water source is very important (Fig. 8). Even the low concentration of dust (0.5 g/m^2) would give 100% mortality if the insect was deprived of water for 24 hours, while the highest concentration (5 g/m^2) did not result in 100% mortality if the treated insect was able to find the water immediately. Also, there was no significant difference in mortality at 0, 1 and 5 hrs in mortality of treated insects at low concentrations ($F=27.7$; d.f=14, 44; $P<0.05$) but a significant difference emerges if they had no water available for 10 hours ($F=27.7$; d.f.=14, 44; $P<0.05$).

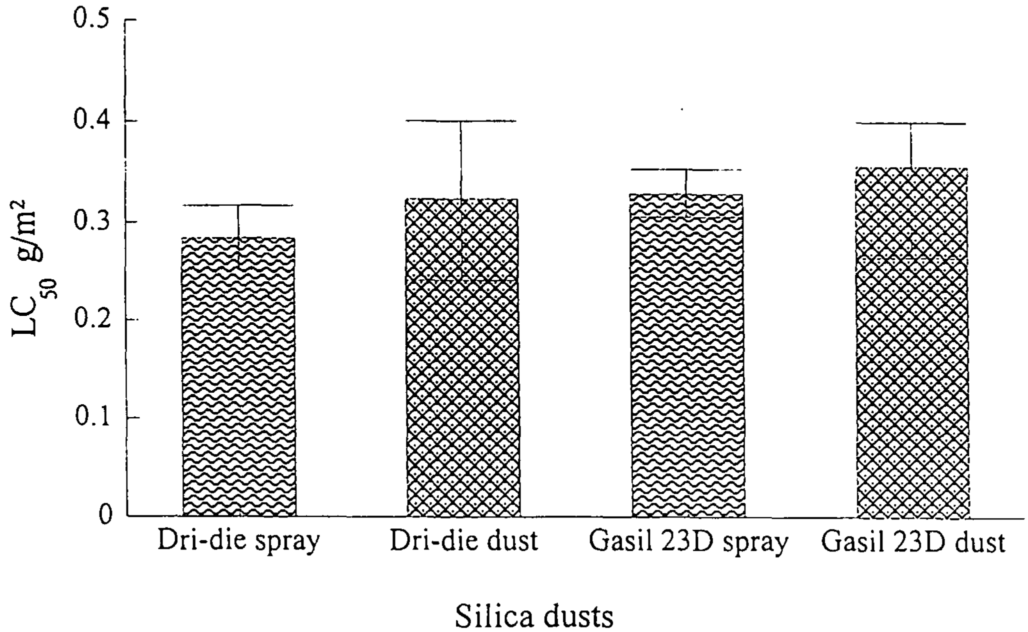

Figure 4. The effect of water on the efficacy of silica dusts.

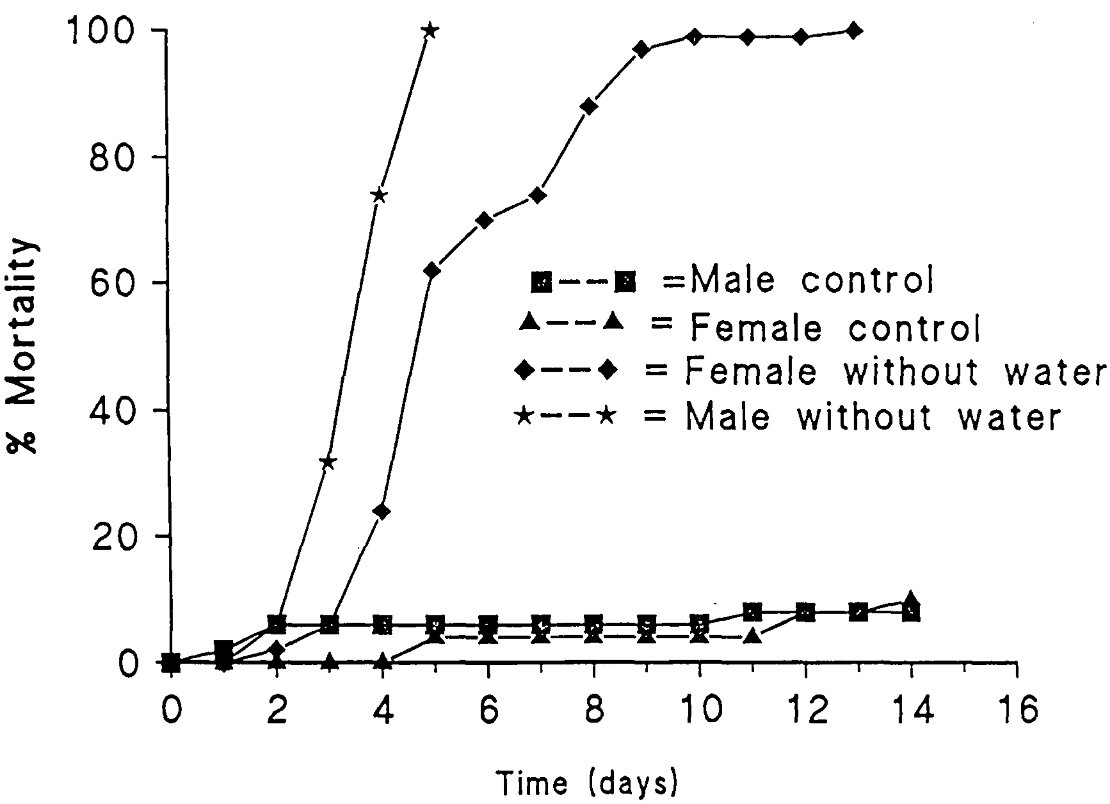

Figure 5. The effect of water deprivation on the survival of male and female German cockroaches.

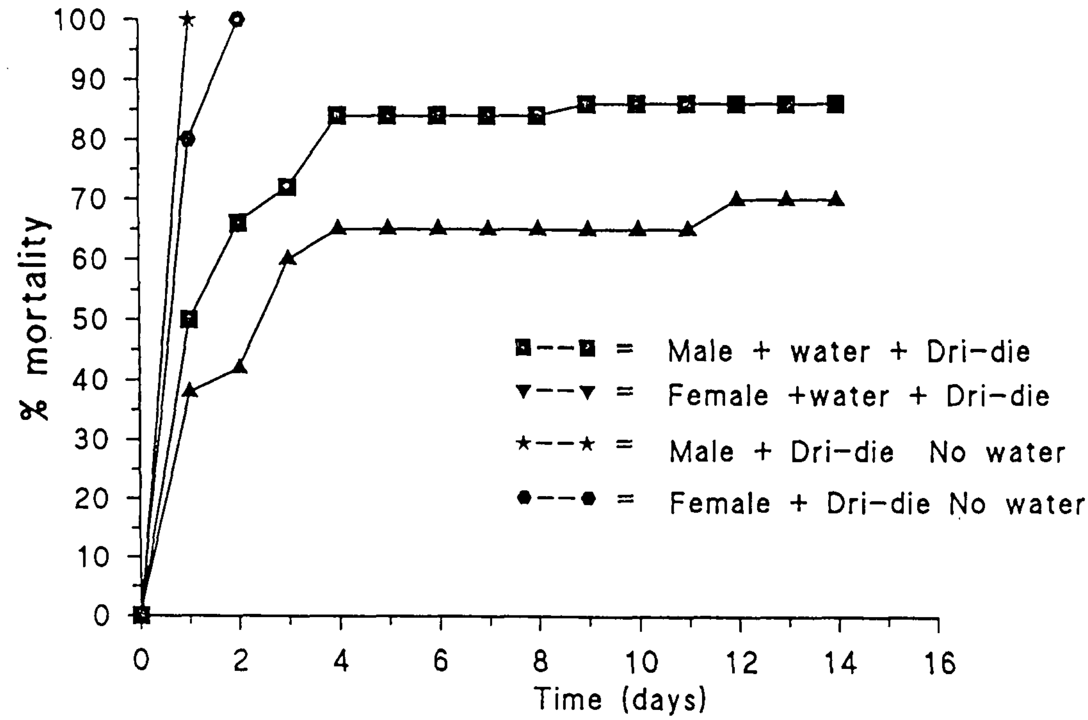

Figure 6. The effect of the presence of free water source on the efficacy of silica dust Dri-die against male and female German cockroaches.

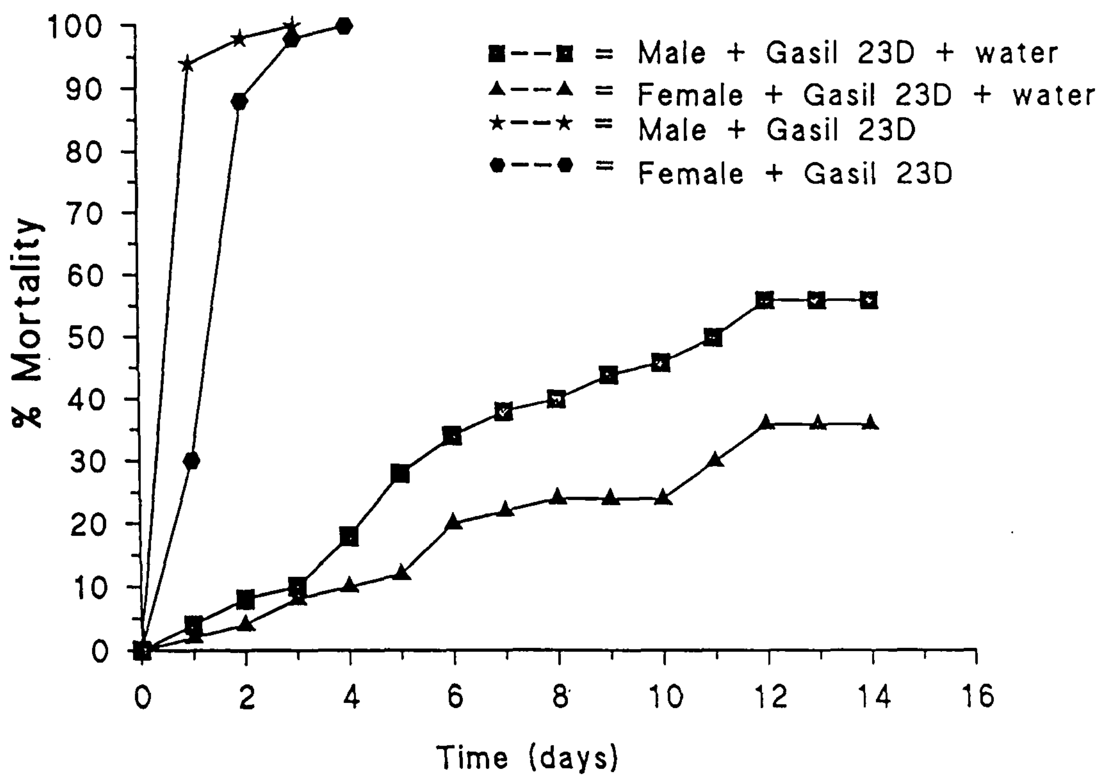

Figure 7. The effect of the presence of free water source on the efficacy of silica dust Gasil 23D against male and female German cockroaches.

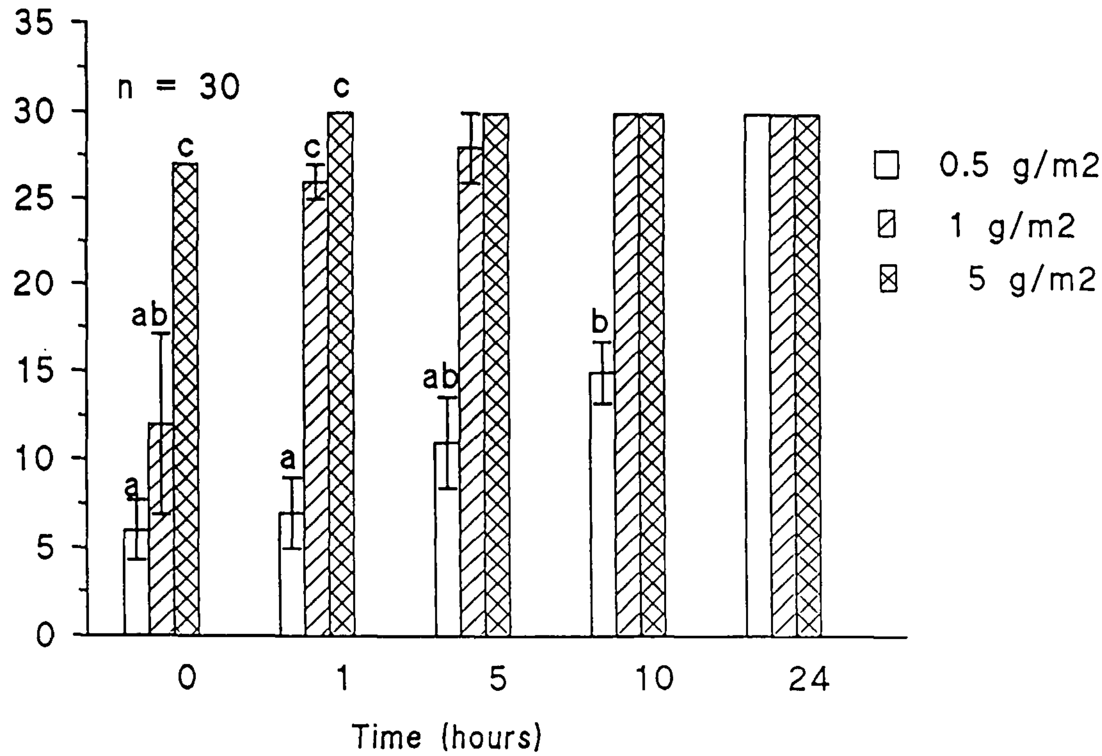

Figure 8. The effect of time interval between dust pickup and finding water source on the mortality of male German cockroaches. Histograms carrying the same letters are not significantly different (P>0.05)

The effect of humidity on silica efficacy

Relative humidity influenced the efficacy of the silica dusts (Tables 3 and 4). A relative humidity greater than 60% had an adverse effect on the efficacy of the unfluorinated silica dust Gasil 23D. No difference in knock down at 40 and 60% r.h. but when r.h. was greater than 70% a difference in KD_{50} values was demonstrated and the KD_{50}s, was longer.

In the case of the fluorinated silica Dri-die there was a difference between the KD_{50} values of 40 r.h. and 60% r.h. but no difference in KD_{50} values between 60 r.h. and 70% r.h. or 70% and 90% r.h.

Mortality was measured in terms of the LT_{50} and LT_{95}. In the case of unfluorinated silica Gasil 23D there was no difference in mortality between relative humidities of 40% and 60%, but at 70% r.h., time to death was increased while at 90% r.h. the LT_{50} was significantly higher than 70% r.h. (i.e. there was no overlap in the 95 confidence limits). For Dri-die there was no difference in the

Table 3. The efficacy of fluorinated (Dri-die) and unfluorinated (Gasil 23D) silica dust at different humidities on the knock-down of male German cockroaches.

Chemicals	r.h.	$KD_{50\,(min.)}$	95% C.I.	Slope±SE	Heterogeneity X^2 d.f.
Gasil 23D	90%	79.48	74.88–83.8	3.51±0.403	0.61; 6
Dri-die	90%	55.48	53.2–57.57	5.346±0.66	0.65; 5
Gasil 23D	70%	50.07	47.47–52.39	4.23±0.57	0.68; 5
Dri-die	70%	52.03	49.84–54.13	4.988±0.611	3.21; 5
Gasil 23D	60%	43.01	40.78–45.11	4.13±0.512	0.846; 5
Dri-die	60%	49.22	47.31–51.5	5.41±0.698	0.377; 4
Gasil 23D	40%	40.53	38.46–42.71	4.14±0.564	1.15; 4
Dri-die	40%	39.63	37.76–41.36	5±0.58	1.75; 5

Table 4. The efficacy of fluorinated and unfluorinated silica dust at different humidities on the mortality of male German cockroaches.

Chemicals	r.h.	$LT_{50\,(min.)}$	95% C.I.	Slope±SE	Heterogeneity X^2 d.f.
Gasil 23D	90%	103.8	100.1–107.34	6.31±0.71	3.5; 5
Dri-die	90%	64.37	62.13–66.42	6.67±0.923	1.25
Gasil 23D	70%	84.13	81.62–86.35	7.85±1.15	3.15; 4
Dri-die	70%	54.24	51.95–56.28	5.48±0.686	1.57; 5
Gasil 23D	60%	59.00	56.9–61	6.08±0.715	3.34; 5
Dri-die	60%	52.00	49.8–54	4.988±0.698	3.2; 5
Gasil 23D	40%	60.07	57.94–62	6.39±0.86	4.6; 4
Dri-die	40%	51.59	49–53.93	4.1±0.5	2.8; 6

LT_{50} or LT_{95} values for relative humidities 40%, 60% and 70% and a slight increase at 90% r.h. (64.4 to 82.3 minutes); a relatively short time in comparison with the LT_{50} and LT_{95} values for the Gasil 23D (103.8, 134.6 min.).

DISCUSSION

The intrinsic toxicity of the dusts tested differed according to their physical properties. A highly significant positive correlation was found between the LC_{50} values and surface area of the particles (r^2=98). The surface area had a significant negative correlation with pore volume ($r^2=-0.922$) and oil adsorption ($r^2=-0.845$). Hence, when the surface area increased the oil adsorption capability decreased, because the small size of the pore volume affects the adsorption of wax molecules from the insect cuticle. Oil adsorption was found to be highly correlated with pore volume ($r^2=0.985$). Similar results have been obtained in studies of *Drosophila pseudoobscura, Blattella germanica, Kalotermes minor* and *Tribolium confusum* (Ebeling, 1961). However, the result contradicts a study on *Dermanyssus gallinae* where good correlations had been found between the surface area of the silicas and their effectiveness ($r^2=0.96$) (Melichar and Willomitzer, 1965). This may be due to the use of dusts with a low specific surface area, ranging between 2–200 m^2g^{-1} in the work of Melichar and Willomitzer (1965) which differed from specific surface area used here which ranged between 290–750 m^2g^{-1}. A significant correlation also has been obtained between the oil adsorption and LC_{50} values ($r^2=0.601$). In another study of the German cockroach it was found that mortality caused by precipitated amorphous silica depends on its oil adsorption capacity while mortality associated with pyrogenic amorphous silica was independent of this capacity (Le Pateroul & Zhou, 1990). Similar results have been obtained with *Tribolium castaneum* (Herbst) (Le Patourel & Singh, 1984). In this study pore volume also shows a good correlation with the LC_{50} values ($r^2=0.77$). However, the particle size of dust tested did not correlate well with the 48 h LC_{50} values ($r^2=0.008$) even though particle size is important in the pick-up of dust as shown in previous work (El-Awami and Dent, 1995).

The formulation of the silica dust Gasil 23D as a liquid suspension did not alter its intrinsic toxicity when applied topically to the cockroach or when sufficient time had elapsed to ensure pick up of a lethal amount of the dust, although the dried spray deposit had a lower speed of action compared with the dust formulation. This may have been due to poor pickup of the spray deposit compared with the dust. Suspending the silica dusts (Dri-die and Silikil-D) in water causes a physical rearrangement of the particles which makes them less available to *Anopheles quadrimaculatus, Culex fatigans* and *Aedes aegypti* than in their original form (Micks, 1960). In other studies dusts that have been soaked and dried again can still kill cockroaches but the time to death is somewhat lengthened (Tarshis, 1959[1 and 2]). Drywood termites sprayed with inert dust showed similar responses (Ebling, 1959). In other work it had been found to depend on the type of silica and surface treated. Amorphous silica deposits applied to different surfaces were equally toxic to *Sitophilus granarius* whether formulated as dry powder or as an aqueous suspension, while pyrogenic silica (cab-o-sil M5) elicited only lower levels of mortality (Gowers & Le Patourel, 1984).

The time for which German cockroaches could survive without water observed in this experiment did not differ greatly from Willis & Lewis (1957). They found that males could live for 8.8±0.4 days and females 11.9±1.5 days without water. Female survival under conditions of water deprivation range between 5 and 9 days depending on their reproductive stage (Durbin & Cochran, 1985). However, whether or not cockroaches have access to water after exposure to silica dust greatly affects efficacy of the dusts especially the unfluorinated silica (Gasil 23D). A significant difference is usually found between the mortality of cockroaches with and without access to water (Le Patourel & Zhou, 1990). Cockroaches that suffer dehydration of about 30 percent of their body moisture, will immediately seek a water source and spend up to 50 percent of their time at the water source, by contrast, under normal conditions, they spend less than 1 percent of their time obtaining water (Caruba, 1988). Such changes in behaviour in response to dehydration were also noted in this study.

The time elapsed between contact with dusted surfaces and access to water was important. The mosquitoes, *Anopheles quadrimaculatus, Culex fatigans,* and *Aedes aegypti* when given access to water immediately following exposure to silica dust (Dri-die), were able to survive until the concentration of dust reached 200 mg/929 cm^2 (Mick, 1960). Beament (1951) found that the cuticle wax of cockroaches is secreted continuously throughout their life in order to make up any losses. Drywood termites *Kalotermes minor* (Hagen) when dusted with sorpative dust and left in a water saturated environment for four days, then placed in an ambient atmosphere, all survived, and in time were able to restore the wax removed by powder (Ebeling & Wagner, 1959).

Water loss from insects is normally proportional to the saturation deficiency of the atmosphere (Buxton, 1932; Johnson, 1942). The results reported here for *B. germanica* are in agreement with Ebeling (1961) who found that at high humidity (72%) the wood termite *Kalotermes minor* (Hagen) required 370 minutes for 100% mortality whilst at a lower humidity (44%) 100% mortality occurred in 260 minutes. Work on Mexican bean beetles showed that the toxicity of dusts used was greater under conditions of high temperature and low humidity (Hunt, 1947). It had also been shown that the percent mortality of *Tribolium castaneum* beetles at 27.8°C, and different relative humidifies in a mixture of wheat and 0.05% r.h. acid-activated kaolin was as follows 25% r.h., 92.3; 50% r.h., 73; 80% r.h., 67.6 and at approximately 0%, 41.2 (Ebeling, 1971). The difference in efficacy between the silica dust Dri-die and Gasil 23D seems to be due to the presence of a monolayer of fluorine which coats the Dri-die particles. The aqueous pathway facilitates the movement of the fluoride ion to the insect body after a portion of the wax is obsorbed by the silica (Ebeling & Wagner, 1959). Unfluorinated silica and fluorinated silica have been found to affect the time required to obtain 100% mortality. However, the variation in humidity did not affect the 100% knock-down time or 100% mortality time for four species of cockroach (German, Brown-banded, Oriental and American) when exposed to silica dust SG67 and silica dust MEF797.00 at four different humidities 25, 50, 75, 100% (Tarshis, 1967).

It is clear from this study that pore volume, oil adsorption and specific surface area are the most important physical characters affecting silica efficacy. Soaking of dust in water does not affect its toxicity when dry again. Relative humidity less than 60% does not affect knock-down or mortality times. This study also indicated that the role of sanitation in cockroach control programmes is very important. The removal of water increases the activity of cockroaches and would increase the probability of their coming across a dusted area and hence increase subsequent mortality through dessication.

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