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EFFECTS OF PHOTOFRIN II® ON ADULTS OF *ERETMAPODITES QUINQUEVITTATUS*

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ABSTRACT. This research was conducted to further assess the efficacy of photosensitizers as adult mosquito control agents. Fourth-stage larvae of *Eretmapodites quinquevittatus* were fed Photofrin® porfimer sodium (PII) (≤3.75 μg/ml) and the resulting adults (parentals) were photoirradiated. These parentals were mated with untreated controls and resulting 1st generation (F_1) progeny were inbred. Comparisons of fecundity and fertility were made between parentals and resulting F_1 progeny. Interbred F_1 adults survived significantly longer than parentals ($P > 0.05$). Parental females laid fewer eggs than F_1 females, and parental eggs hatched at a significantly lower rate than eggs of F_1 females ($P < 0.01$). Neither PII nor any effects of PII seem to be transferred from parent to offspring. Reduced fecundity and fertility may be due to reduced energy levels caused by exposure to PII. Experimental adults fed PII exhibited significantly reduced survivorship when compared to untreated controls ($P < 0.001$). Fertility did not differ when compared to controls, but experimental adult fecundity was significantly less than control fecundity for the constant photoirradiation group.

KEY WORDS Photosensitization, photochemical, photoreactive, photoactive, photochemistry, photosensitizer, insect control

INTRODUCTION

Photofrin® porfimer sodium (PII) could be toxic to adult insects without photoirradiation, because it was toxic to larvae not provided photoirradiation. The potential for light to pass through the scales of the adult body and activate the most destructive light reaction (with photoirradiation) pathways of PII would be minimal. The dark reactions (no photoirradiation) pathways would be the only reactions leading to cellular destruction in adults. Adults might ingest PII in a sugar solution, because PII is reconstituted with 5% glucose, and sugar is provided as a carbohydrate source for adults. Our focus was on the effect of PII on adult life span, egg production (fecundity), and fertility.

Photosensitizers are compounds requiring direct interaction with light and molecular oxygen to produce highly reactive oxygen species (primarily singlet oxygen). These compounds are toxic to all living things because singlet oxygen reacts with many types of biological molecules (membrane lipids, cytochromes, nucleic acids; Kessel 1981, 1986). Natural and synthetic photosensitizers are equally destructive (Arnason et al. 1981, Sakurai and Heitz 1982, Kagan et al. 1987).

One approach to photosensitizing cells involves providing a natural or synthetic photosensitizer, such as PII, to living organisms or to target cells in sufficient quantities that when exposed to light and molecular oxygen phototoxic products are produced and the organism is injured or killed. These are the light reactions, which are the most destructive to cells. Another approach involves use of photosensitizer, such as PII, as stated above, but without exposure to or with little exposure to light. Little inquiry has been initiated concerning this mode of PII action. Toxicity is known to be associated with the dark reactions, but this activity is inconsequential when compared to the enormous damage caused when light is added (light reactions). Because of this, all research has focused on the light reactions and finding ways to make this activity cell specific (Dougherty 1987, Rebeiz 1995).

Porphyrins or hematoporphyrin derivatives possess alternating double bonds around 4 pyrrole rings resulting in a conjugated 18 π electron system that provides high stability. The active component of PII seems to be a 2- to 3-unit oligomer that absorbs light in the 400- to 630-nm range of the spectrum (Dougherty 1987, Byrne et al. 1990). This oligomer, when activated by light in the presence of molecular oxygen, produces photoproducts destructive to cells.

Photodynamic effects of porphyrins are due to their photoexcitable nature. The ground-state porphyrin is photoexcited to the singlet state. Next, intersystem crossing of an electron from the excited singlet state to the excited triplet state occurs. The excited triplet state has lower energy than the singlet state, but has a longer half-life. Now the excited triplet sensitizer may undergo 1 of 2 reactions—type I or II (Foote 1990). Indirect evidence indicates the primary pathway for cellular destruction is the type II reaction. Type II reactions occur when triplet sensitizer interacts with ground-state oxygen to produce excited singlet oxygen (Foote 1990). Singlet oxygen is extremely reactive and will react with electron-rich substrates yielding peroxides and other oxidized species (Spikes 1985, Foote 1990). The effect of these oxidized species is disruption of metabolism, nucleic acids, and membranes (Foote 1990).

Barbieri (1928) demonstrated that aquatic larvae of *Anopheles maculipennis* Meigen were killed when exposed to halogenated fluorescein deriva-

tives, erythrosin, and eosin and then illuminated. Schildmacher (1950) confirmed the above work when he photosensitized *An. maculipennis, Anopheles superpictus* Grassi, and *Aedes aegypti* (L.) mosquitoes with rose bengal, erythrosin, fluorescein, and eosin. Forty years later, Hartberg and Judy (1990) showed that larvae of *Eretmapodites quinquevittatus* Theobald were killed by PII and that onset of effects was directly proportional to concentration of PII and length of exposure to PII. Helleck and Hartberg (unpublished) also witnessed increased difficulty in larval and pupal extrication, but were unsure whether this was due to improper chitin formation or reduced energy levels. For an excellent review of the history of insect photosensitization see Heitz and Downum (1987).

This study examined the effects of Photofrin® II or Photofrin® porfimer sodium (PII) on the adult mosquito *Er. quinquevittatus.* This species is native to sub-Saharan Africa and Madagascar (Gillett 1972) and may transmit arboviruses (Macnamara 1953, McIntosh et al. 1961, Gilotra and Shah 1967, Serie et al. 1968, Brottes et al. 1969).

Eretmapodites quinquevittatus was chosen as the test organism because it is easily maintained in the laboratory and has been studied extensively (Hartberg and Gerberg 1971; Hartberg and Johnston 1977, 1979; Johnston and Hartberg 1981; Hartberg and Faircloth 1983; Helleck et al. 1993, 1994, 1996, 1997).

This research was conducted to further assess the efficacy of photosensitizers as control agents against adult mosquitoes. Resistance to and lack of effectiveness of insecticides by mosquitoes occurs and is life-threatening, because mosquitoes are known vectors of disease (Georghiu and Lagunes-Tejeda 1991, Raymond et al. 1993, Pasteur and Raymond 1996). Photoactive compounds could provide effective photoinsecticides for future use in insect control (Spikes 1985, Rebeiz et al. 1995).

MATERIALS AND METHODS

Laboratory colonies and cultures of *Er. quinquevittatus* (EQ-MIXED) were maintained at the Medical Entomology Research Laboratory at Baylor University in a walk-in environmental chamber set at 25°C, 80 ± 5% relative humidity, and a 14:10 h light:dark photoperiod. The EQ-MIXED adult colony was provided sugar cubes as a carbohydrate source, and females were provided anesthetized mice every 2–3 days for blood meals. This colony was established by W. K. Hartberg from larvae collected from a tree hole in the Kisutu section of Dar es Salaam, Tanzania, in July 1969 (Hartberg and Gerberg 1971).

Eggs were collected from the EQ-MIXED colony by providing ovipositing females with moist, bleached, paper towels (oviposition or egg papers) lining the inside of 250-ml beakers or half-pint (279.3-ml) Ball™ jars placed inside of the colony cage. Collected eggs (on egg papers) were a mixture of autogenous and anautogenous eggs, were not stored, and hatched ≈48 h after oviposition in 250-ml beakers or half-pint (279.3-ml) Ball jars.

First-stage larvae were transferred to Nalgene® pans (VWR Scientific Products, Suwanee, GA) (32 × 26 × 6 cm or 26 × 16 × 6 cm) half filled with tap water (tH_2O) and reared to the 4th larval or adult stages. During development larvae were provided ≈0.25 ml of larval food (Wardley's® fish food and water, 2:1 ratio) placed at the bottom of Nalgene pans. Experimental adults were provided sugar cubes, and females were provided anesthetized mice for blood meals. The 1st blood meal was provided when autogenous egg production ceased and subsequent blood meals were provided every 2–3 days. All adults were photoirradiated with 8 (15-W) Philips® fluorescent lamps in parallel array (1.12 mW/cm², 350–800 nm), placed ≈25 cm above the container.

Toxicity of photoirradiated PII on adults when fed PII as 4th-stage larvae: Fifty 4th-stage larvae (≈6 days of larval development) each were fed larval food and 3.75 μg/ml of PII (reconstituted with dextrose), and were cultured in 1 of 3 different osmotic solutions until emergence of adults: hypotonic (= distilled water), hypertonic (= 1.1× *Ae. aegypti* saline solution), and isotonic (= *Ae. aegypti* saline solution) (Hayes 1953). These 3 osmotic solutions were used because we found that different osmotic conditions coupled with the effects of PII have different effects on larval survivorship (Helleck et al. 1997). Additionally, 50 larvae were given larval food and either cultured in a hypertonic solution containing no PII (control 1) or tH_2O containing no PII (control 2) until emergence of adults. Fourth-stage larvae fed PII that developed into adults (parentals) were mated with control 2 adults. Resulting F_1 adult siblings were interbred. Adult life span, fecundity, and fertility were determined and analyzed for these 2 generations of adults.

Toxicity of nonphotoirradiated PII on adults: Twenty-five adult (≈12–13 days of development) males and 25 adult females each were randomly placed in 6 1-gallon (3.8-liter) cages. Three of the cages (experimentals) included a 50-ml beaker containing 90 μg/ml of PII (reconstituted with dextrose; 20-ml final volume). The other 3 cages (controls) included a 50-ml beaker containing a 5% dextrose solution (20-ml final volume), but no PII. One experimental and 1 control cage were placed in complete darkness, 1 experimental and 1 control cage were placed under constant photoirradiation (= 1.12 mW/cm², 350–800 nm; positioned 25 cm above the container), and 1 experimental and 1 control cage were placed under intermittent photoirradiation (= environmental chamber light, 14:10 h photoperiod).

Statistical analysis: Life spans of parentals were compared to those of F_1 adults by the log-rank or chi-square test (Anderson et al. 1980). Fecundity of

Table 1. Adult life span in days, fecundity (eggs laid), and fertility (percent hatch) for autogenous (auto) and anautogenous (anauto) eggs of *Eretmapodites quinquevittatus* larvae (3rd/4th stage) developing into adults after being exposed to 3.75 μg/ml of Photofrin porfimer sodium II and hypotonic or isotonic solution. Experimental parental (P_1) adults were crossed with parental controls of opposite sex. Standard errors are in parentheses.[1]

Experiment no.	P_1 M × F	Life span (days) (M/F)	Eggs laid (auto/anauto)	Eggs hatched (auto/anauto)	Percent hatch (auto/anauto)
1	Cont × Hypo	9/57	0/25	0/20	0/80
2	Iso × Cont	2/9	0/3	0/2	0/66.6
3	Iso × Cont	1/57	0/0	0/0	0/0
4	Cont × Hypo	27/57	0/29	0/0	0/0
5	Cont × Hypo	18/54	0/14	0/1	0/7
6	Cont × Hypo	7/64	0/26	0/20	0/77
7	Cont × Hypo	11/35	0/12	0/0	0/0
8	Cont × Hypo	11/64	0/3	0/0	0/0
9	Cont × Hypo Batch 1	24/44	0/28	0/27	0/96
9	Cont × Hypo Batch 2	Same	0/63	0/37	0/59
Mean (average)		12.2 (3.0)/ 49.0(5.8)	25.3 (10.0)	13.3 (7.9)	52.7

[1] M, male; F, female; Cont, control; Hypo, hypotonic; Iso, isotonic.

parentals was compared to that of F_1 adults by comparison of average eggs laid/female. Fertility of parentals and F_1 adults were compared by 1-way analysis of variance (ANOVA) (arcsine transformation).

Adult life span, fertility, and fecundity were determined for each 1-gallon (3.8-liter) cage. Adult life span of experimentals was compared to that of controls by the log-rank or chi-square test (Anderson et al. 1980). Fecundity of experimental adults was compared to that of controls by comparison of average eggs laid/female. Fertility of experimental and control adults was compared by 1-way ANOVA (arcsine transformation).

RESULTS

Toxicity of photoirradiated PII on adults when fed PII as 4th-stage larvae

Two isotonic and 7 hypotonic 4th-stage larvae developed into parental adults and were mated with control 1 parentals of the opposite sex (Table 1). None of the hypertonic males or females survived to the adult stage. The effect of differences in osmotic concentrations are fully discussed in Helleck et al. (1997). Experimental parentals did not differ significantly in life span when compared to control 1 parentals ($P > 0.05$). None of the experimental parental females laid autogenous eggs but did lay 203 anautogenous eggs for a mean of 25.3 (SE = 10.0) anautogenous eggs/female (Table 1). Fertility for these eggs was 52.7%. The F_1 adults lived significantly longer than parentals ($P > 0.05$; Table 2). Each F_1 female laid an average of 26.1 autogenous and 200.5 anautogenous eggs (Table 2). Fertility for eggs laid by parental females (52.7%) was significantly less than fertility of eggs laid by F_1 females (94% autogenous and 82.7% anautogenous; $P < 0.05$; Table 2). All control 1 and control 2 4th-stage larvae developed into adults.

Toxicity of nonphotoirradiated PII on adults

Survival rates of experimental adults fed PII (90 μg/ml) as adults with no photoirradiation, constant photoirradiation, or intermittent photoirradiation did not significantly differ for males or females ($P > 0.05$; Figs. 1 and 2). Survival rates of experi-

Table 2. Mean life span in days, fecundity (eggs laid), and fertility (percent hatch) of autogenous (auto) and anautogenous (anauto) eggs laid by 1st. generation (F_1) females of *Eretmapodites quinquevittatus*. First-generation adults were interbred. Standard errors are in parentheses.[1]

Experiment no.	F_1 M × F	Mean life span (d) (M/F)	Eggs laid (auto/anauto)	Eggs hatched (auto/anauto)	Percent hatch (auto/anauto)
1	9 M × 9 F	52.8(9.0)/82.8(14.4)	297/2,640	286/2,461	96/93
2	1 M	86.0(0.0)/0	0/0	0/0	0/0
6	6 M × 5 F	39.6(8.5)/58.8(16.3)	63/295	62/212	98/72
9	5 M × 13 F, Batch 1	37.4(2.7)/72.7(13.6)	350/2,948	327/2,042	93/69
9	5 M × 10 F, Batch 2	50.8(11.2)/38.8(10.3)	256/1,536	234/1,422	91/92
Mean (average)		47.7(4.5)/64.1(7.2)	26.1/200.5	24.5/165.8	94/82.7

[1] M, male; F, female.

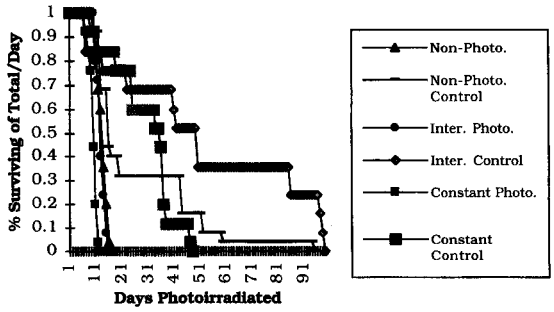

Fig. 1. Percent (%) survivorship of adult male *Eretmapodites quinquevittatus* exposed to 90 μg/ml of Photofrin porfimer sodium (PII). Non-Photo. = PII, no photoirradiation; Inter. Photo. = PII, 14:10 h light:dark cycle of photoirradiation; Constant Photo. = PII, continuous photoirradiation; Controls = no PII, same photoirradiation. n = 25.

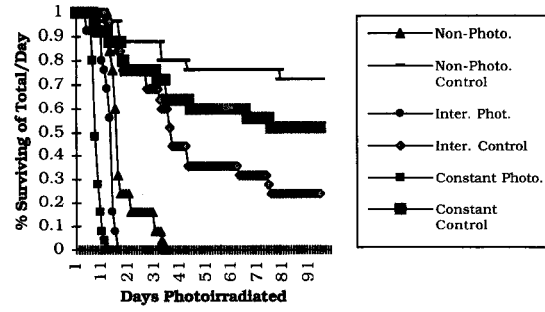

Fig. 2. Percent (%) survivorship of adult female *Eretmapodites quinquevittatus* exposed to 90 μg/ml of Photofrin porfimer sodium (PII). Non-Photo. = PII, no photoirradiation; Inter. Phot. = PII, 14:10 h light:dark cycle of photoirradiation; Constant Photo. = PII, continuous photoirradiation; Controls = no PII, same photoirradiation. n = 25.

mental adults were significantly lower than for control adults in all 3 photoirradiation settings ($P < 0.001$). Fecundity was lowest for experimental females exposed to PII in the constant photoirradiation group and fertility did not differ (Table 3).

DISCUSSION

Toxicity of photoirradiated PII on adults when fed PII as 4th-stage larvae

The importance of this line of investigation is evident when realizing that even lower concentrations of PII (1–5 μg/ml, sublethal) might not kill larvae (or other nontarget organisms), yet might adversely affect developing adults or later generations (Table 1). Although PII fed at 1 stage can adversely effect subsequent stages of development, it was not clear whether PII fed during 1 generation could adversely effect a subsequent generation.

Although survivorship of experimental parentals did not significantly differ ($P > 0.05$) when compared to their control 1 mates, they were affected in other ways. None of the parental females laid autogenous eggs, which differs greatly from a range of 53.3–64.5 autogenous eggs/female that is reported for colonized *Er. quinquevittatus* females (Helleck et al. 1996). Anautogenous fecundity was also reduced. Helleck et al. (1996) reported that colonized females of *Er. quinquevittatus* averaged 137.1–244.8 anautogenous eggs/female, whereas the 8 females of this experiment laid an average of 25.3 eggs/female (Table 1). Anautogenous egg fertility (percent hatch) was also reduced. Helleck et al. (1996) reported fertility of 87.8 and 74.5% for autogenous and anautogenous eggs, respectively. Females from this experiment laid anautogenous eggs that hatched at a 53% rate (Table 1). First-generation females laid an average of 24.5 and 165.8 autogenous and anautogenous eggs, respectively (Table 2). Although autogenous egg production was less than previously reported, anautogenous egg production was consistent with that of previous reports (Helleck et al. 1996). Fertility levels of 94% and 83% for autogenous and anautogenous eggs were consistent with previous reports as well (Helleck et al. 1996; Table 2). We did not detect PII fed to 1 generation having any effect on subsequent generations.

Toxicity of nonphotoirradiated PII on adults

Adults of *Er. quinquevittatus* are affected by PII. As was initially hypothesized, the dark reactions were most important in killing adults that are fed PII. This is a plausible assumption, because light should not easily penetrate the scales of an adult

Table 3. Fecundity and fertility of adult females of *Eretmapodites quinquevittatus* exposed to 90 mg/ml of Photofrin porfimer sodium (PII).[1]

	Non-photoirradiation		Intermittent photoirradiation		Constant photoirradiation	
	PII	Control	PII	Control	PII	Control
No. eggs laid	1,249	1,642	1,207	1,533	702	1,158
No. eggs hatched	1,111	1,445	1,038	1,380	667	1,054
Percent hatch	89	88	86	90	95	91

[1] Nonphotirradiation, PII with no photoirradiation; intermittent photoirradiation, PII with 14:10 h light:dark photoirradiation cycle; constant photoirradiation, PII with constant photoirradiation; controls, no PII with same photoirradiation.

mosquito and because different exposures or intensities of light had no significant affect on the survival rate of adults fed the same concentration of PII. Control adults survived significantly longer than experimental adults in all 3 light settings (Figs. 1 and 2). Adults living in constant photoirradiation laid significantly fewer eggs than controls in constant photoirradiation or any of the other experimental groups ($P < 0.05$; Table 3). Fertility was not different among any of the experimental or control groups. The females in constant photoirradiation may have laid fewer eggs because of reduced energy levels caused by reduced energy or food absorption by damaged gastric epithelia (Helleck and Hartberg 1999) due to constant photoirradiation their entire lives.

Adult life span and fecundity were significantly reduced when adults ingested PII. A solid form of photosensitizer and carbohydrate placed in areas (hanging under eaves of the home, and so on) where adult mosquitoes feed or rest might be useful in reducing the number of females or in reducing a female mosquito's ability to lay eggs.

REFERENCES CITED

Anderson S, Auquier A, Hauck WW, Oakes D, Vandaele W, Weisberg HI. 1980. *Statistical methods for comparative studies: techniques for bias reduction* New York: John Wiley & Sons.

Arnason T, Swain T, Wat C-K, Graham EA, Partington S, Towers GHN. 1981. Mosquito larvicidal activity of polyacetylenes from species in the Asteraceae. *Biochem Syst Ecol* 9:63–68.

Barbieri A. 1928. Sensibilizadaroes fluorescentes como larvicidas. Accion fortodynamica de la luz. *Riv Malariol* 7:456.

Brottes HA, Rickenbach P, Bres MC, Williams J, Salaun J, Ferrara L. 1969. A new arbovirus prototype Okola virus YM-50-64 isolated in the Cameroons from mosquitoes human new record—*Eretmapodites chrysogaster. Ann Inst Pasteur* 116:543–551.

Byrne CJ, Marshallsay LV, Ward AD. 1990. The composition of Photofrin II. *Photochem Photobiol* 6:13–27.

Dougherty TJ. 1987. Studies on the structure of porphyrins contained in Photofrin II. *Photochem Photobiol* 46: 569–574.

Foote CS. 1990. Chemical mechanisms of photodynamic action. Proceedings of the SPIE Institute. *Adv Optic Technol Photodynam Ther IS* 6:115–126.

Georghiu GP, Lagunes-Tejeda A. 1991. *The occurrence of resistance to pesticides in arthropods. An index of cases reported through 1989* Rome, Italy: Food and Agriculture Organization.

Gillett JD. 1972. *Common African mosquitoes* London: John Swain and Co.

Gilotra SK, Shah KV. 1967. Laboratory studies on transmission of Chikungunya by mosquitoes. *Am J Epidemiol* 86:379–385.

Hartberg WK, Faircloth WH. 1983. Mitotic chromosomes of the mosquito *Eretmapodites quinquevittatus* Theobald. *Mosq Syst* 15:325–329.

Hartberg WK, Gerberg EJ. 1971. Laboratory colonization of *Aedes simpsoni* and *Eretmapodites quinquevittatus. Bull WHO* 45:850–852.

Hartberg WK, Johnston KW. 1977. Red-eye, a sex-linked mutant in the mosquito *Eretmapodites quinquevittatus* Theobald. *Mosq News* 37:725–728.

Hartberg WK, Johnston KW. 1979. White-eye, a mutant in the mosquito *Eretmapodites quinquevittatus* Theobald. *Mosq News* 39:371–373.

Hartberg WK, Judy MM. 1990. Photosensitization of mosquito larvae with DHE. In: Proceedings of the 1990 South Central Regional Mosquito Control Conference 34th Annual Meeting. p 22.

Hayes RO. 1953. Determination of a physiological saline solution for *Aedes aegypti. J Econ Entomol* 46:624–627.

Heitz JR, Downum KR, eds. 1987. Light-activated pesticides. ACS Symposium Series. Washington, DC: American Chemical Society.

Helleck AM, Hartberg WK. 1999. Site of Photofrin II® photosensitization in larvae of *Eretmapodites quinquevittatus* Theobald. *J Am Mosq Control Assoc* 15:437–445.

Helleck AM, Hartberg WK, Baldridge RS. 1997. Photosensitization of *Eretmapodites quinquevittatus* Theobald (Diptera: Culicidae) eggs and larvae with Photofrin II®. *J Am Mosq Control Assoc* 13:292–295.

Helleck AM, Hartberg WK, Vodopich D. 1993. Daily survivorship and life span of the mosquito *Eretmapodites quinquevittatus* Theobald (Diptera: Culicidae) under laboratory conditions compared to *Aedes aegypti, Aedes albopictus,* and *Aedes bahamensis. Bull Soc Vector Ecol* 18:109–113.

Helleck AM, Hartberg WK, Vodopich D. 1994. Variations in development times of *Eretmapodites quinquevittatus* Theobald (Diptera: Culicidae). Bull Soc Vector Ecol 19: 100–103.

Helleck AM, Hartberg WK, Vodopich D. 1996. Fecundity, fertility, and development stage survivorship of *Eretmapodites quinquevittatus. J Am Mosq Control Assoc* 12:137–141.

Johnston KW, Hartberg WK. 1981. Polygenic inheritance of variation in scale pattern of the abdominal sterna of *Eretmapodites quinquevittatus* (Diptera: Culicidae). *J Med Entomol* 18:300–312.

Kagan J, Kagan ED, Patel S, Perrine D, Bindokas V. 1987. The phototoxicity of alpha-terthienyl in eggs, larvae, and pupae of the mosquito *Aedes aegypti. J Chem Ecol* 13:593–604.

Kessel D. 1981. Transport and binding of hematoporphyrin derivative and related porphyrins by murine leukemia L1210 cells. *Cancer Res* 41:1318–1323.

Kessel D. 1986. Sites of photosensitization by derivatives of hematoporphyrin. *Photochem Photobiol* 44:489–493.

Macnamara FN. 1953. The susceptibility of chicks to Semliki Forest virus (Kumba strain). *Ann Trop Med Parasitol* 47:9–12.

McIntosh BM, Kokernot RH, Paterson HE, De Meillon B. 1961. Isolation of spondweni virus from four species of culicine mosquitoes and a report of two laboratory infections with the virus. *S Afr Med J* 35:647–650.

Pasteur N, Raymond M. 1996. Insecticide resistance genes in mosquitoes: their mutations, migration, and selection in field populations. *J Hered* 87:444–449.

Raymond M, Poulin E, Boiroux V, Dupont E, Pasteur N. 1993. Stability of insecticide resistance due to amplification of esterase genes in *Culex pipiens. Heredity* 70: 301–307.

Rebeiz CA, Gut LJ, Lee K, Juvik JA, Rebeiz CC, Bouton

CE. 1995. Photodynamics of porphyric insecticides. *Crit Rev Plant Sci* 14:329–366.

Sakurai H, Heitz JR. 1982. Growth inhibition and photooxidative toxicity in the house fly, *Musca domestica* L., caused by xanthene dye in larval growth medium and after injection. *Environ Entomol* 11:467–470.

Schildmacher H. 1950. Uber photosensibilisierung von stechmuckenlarven durch fluoreszierende Farbstoffe. *Biol Zentralbl* 69:468.

Serie CL, Andral J, Casals MC, Williams P, Bres MC, Neri P. 1968. Studies on yellow fever in Ethiopia. 5. Isolation of viral strains from arthropod vectors. *Bull WHO* 38:873–877.

Spikes JD. 1985. The historical development of ideas on applications of photosensitized reactions in the health sciences. In: Bensasson RV, Lind EJ, Jori G, Truscott TG, eds. *Primary photoprocesses in biology and medicine* New York: Plenum Press. p 124–144.