Boric Acid as a Safe Insecticide for Controlling the Mediterranean Fruit Fly *Ceratitis Capitata* Wiedemann (Diptera: Tephritidae)

Naimah Asid Alanazi
Department of Biology, College of Sciences, University of Ha'il, Saudi Arabia
n.alenezy @uoh.edu.sa (corresponding author)

Received: 22 August 2023 | Revised: 7 September 2023 | Accepted: 9 September 2023

 DOI: https://doi.org/10.48084/etasr.6305

ABSTRACT

In promising experiments, boric acid has been tested as a safe and environmentally friendly insecticide for controlling Ceratitis capitata Wiedeman, a mediterranean fruit fly diptera belonging the Tephritidae family. Obtaining encouraging results can partially solve insecticidal pollution caused by chemical insecticides. Boric acid was applied in five baits that were, water, 5 and 10% sugar solutions, and 2.5 and 5% protein solutions on just emerged and 24-hour-old flies. For each bait, boric acid was presented by successive concentrations of 0.5%, 1%, 1.5%, and 2%. After 24 hours, the aged-fly death percentage ranged from 12.2 to 69.4 % and from 48 to 99.4% after 48 hours for just-emerged flies. However, for 24-hour-old flies, the percentage of death ranged from 32.6 to 90.4% after 24 hours and 65 to 99.6% after 48 hours. The current study shows the existence of a a direct proportionality between death percentage and the concentration of boric acid in the five baits, as death percentage increased with boric acid concentration. In addition, different baits had some effect on death percentage, but without a noticeable correlation. To avoid direct contact with the host plant and the boric acid-based baits, it is strongly encouraged to utilize boric acid in medfly control methods like the mass trapping technique.

Keywords-Mediterranean fruit fly; ceratitis capitata; control; boric acid

I. INTRODUCTION

Fruits represent a very important component of world agricultural production due to their high export returns, high production, and income per unit area [1]. However, medfly Ceratitis capitata (Wiedemann) (Diptera: Tephritidae) as an invasive pest of horticultural crops, has become very dangerous [2-8]. The great restrictions on insecticide use from one the one hand, and the high demand for healthy food all over the world on the other, a new generation of environmentally friendly fruit fly control techniques is emerging [9].

Boron can be found in combination with other elements [10]. It is the main constituent of boric acid and its chemical relatives. These can be found in a variety of water environments like oceans, seas, rivers, groundwater and streams; as well as in the soils [11]. It is also an essential nutrient for plants [12] and human food [13]. Boron compounds are often recommended low-toxicity pesticides for controlling a wide range of damaging pests such as algae, fungi, mites and insects, and even some vascular plants [14]. Compared to pesticides, boric acid is a low-toxicity, non-volatile mineral with insecticidal, fungicidal, and herbicidal properties that make it a safer replacement for highly volatile synthetic chemical pesticides. It comes in naturally occurring compounds, as opposed to many insecticides, which contain synthetic substances [15]. Boric acid and its compounds are stable and do not break down, unlike pesticides composed of complex molecules. These substances easily and quickly degrade in water and soil to become borates, which is boron in its native state [16].

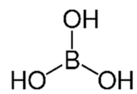

Fig. 1. Boric acid.

Boric acid is a low-toxicity pesticide, has low insect resistance and does not repel insects, so it is considered an ideal pesticide in bait products [17]. The integrated pest control (IPM) program, which combines sanitary, cultural, mechanical, and biological activities, also makes use of some boric acid [12]. It was registered as a pesticide in the US in 1948 and and in, boric acid or any of its sodium salts are an active component in about 189 registered pesticide formulations [17]. Boric acid is applied in many medical and agricultural fields and industries, since, when used in low concentrations, birds, aquatic creatures, beneficial insects (honey bees and biological control agents), and mammals are not harmed by it, but it is detrimental to small animals [18]. It is employed as a inorganic pesticide on various dangerous insects such as ants, cockroaches, and mosquitos, and it also has a stomach toxic effect [19]. Increasing nutrient consumption is necessary because it interferes with the absorption of vitamins, nucleotides, and carbohydrates by forming complexes with these substances. As its negative effects on insects is that it acts as a stomach toxin, it can be used in a food-attracting bait formulation. When used in the form of dry powder and ingested, it causes death a few days later due to malnutrition and dehydration [14, 15, 17]. In [20], Attractive Toxic Sugar Baits (ATSBs) that contained the harmful active ingredient boric acid, were used. It was suggested to be an efficient bait, since it is environmentally friendly compound [21-23]. In [21, 22, 24-26], recent successful ATSB evaluations were performed in tropical environments. In terms of plants, all species require small amounts of boron, it is "one of the more essential elements for plant growth" [27], but high concentrations are toxic since it desiccates the plant and interrupts photosynthesis. The signs of boron poisoning include leaf burn, dead patches inside of fruits, dead parts of bark, and stem dieback [28-29]. They also inhibit the production of spores by fungus. Also, for a long period, either alone or in combination, for vermin control [21]. For mammals, such as dogs and rats, they are toxic to the testes at high dosages, producing histopathological alterations and even sterility. Because it can be toxic if intentionally consumed, it must be stored away from food, children, and pets, not breathed in the dust when applied and used in locations where it will not move about [30]. The bioactive element boron, which is advantageous for many species, belongs to a separate group (Group D) than boron oxide and boric acid (BA, H3BO3) [31]. In [14], tests were performed on the peach fruit fly *Bactrocera zonata* Saunders (Diptera: Tephritidae) using boric acid as an effective pesticide with extremely optimistic outcomes that served as the foundation for the current investigation.

Synthetic baits contain a mixture of boric acid and other nutrients, such as sugar and proteins that are more pest-attractive, and provide effective results in pest control [32-33]. This study aimed to test different bait mixtures made of water, sugar, or proteins and boric acid on the percentage of deaths of the Mediterranean fruit fly *Ceratitis capitata.*

II. MATERIALS & METHOD

A. *Fly Strain*

This study used laboratory strains of Mediterranean fruit flies that were reared in the laboratory of the biology department using a synthetic larval meal that contained the following ingredients:

- Sugar 8.45%: source for carbohydrate
- Sterilized dried yeast 8.45%: source for protein
- Grain bran 33%: agent for bulking
- Benzoate of sodium 0.3%
- Water with vitric acid 0.3%
- Water 50%.

The adult flies were fed normal food sources for adult flies including water, sugar, and hydrolyzed protein (4:1).

B. *Experiments*

1) *The Solutions*

The experiments were carried out with four different concentrations of boric acid (0.5%, 1%, 1.5%, and 2%), that was used to treat medflies (just emerged and 24 hours after emergence).

2) *Cages*

A 1000 ml transparent plastic cube, with a piece of fiber net fixed to the top (in the lid), was used to supply insects with different formulations and aeration. For each treatment, five replicates were produced. The insects were placed at 100 flies per cage.

3) *Data Collection*

Data were recorded after 24 and 48 hours.

4) *Data Statistical Analysis*

Data of calculated death percentages were examined using a one-way ANOVA test in IBM SPSS Statistics version 23.

III. RESULTS

A. *Just Emerged Flies Supplied with Boric Acid Formulations*

1) *Death Percentage after 24 Hours*

Table I shows the results obtained, indicating a direct proportionality between death percentage and concentration of boric acid in the five feeding regimes. The death percentage increased as the boric acid concentration increased but with a significant difference between the 4 concentration groups within the 5 feeding regimes. For water feeding regime 0.5 % boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% with means of 12.2, 43, 54.2 and 63.2% respectively. For 5% sugar solution regime, 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5% and 2.0% with means of 18.2, 22.4, 43.4 and 69.4%, respectively. For 10% sugar solution regime 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% with means of 15.8, 32.6, 44.6 and 47.8%, respectively. For 2.5% protein solution regime, 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% with means of 28, 50, 53.8 and 65% respectively. For 5% protein solution regime 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% with means of 31, 36.2, 62 and 67.5%, respectively. For the 2.5% protein solution regime, the death percentage means were 28, 50, 53.8, and 65% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 5% protein solution regime, the death percentage means were 31, 36.2, 62, and 67.5% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. The lowest death percentage was observed with 0.5% boric acid in the water feeding regime with a mean of 12.2 %, while the highest death percentages were observed with 2% boric acid in the 5% sugar solution and the 5% protein solution feeding regimes with means of 69.4 and 65%, respectively. The results show that the feeding regimes have some effect on death percentages, since there was a significant difference between them under the same boric acid concentration, without any noticeable correlation between death percentage and feeding regime.

TABLE I. DEATH PERCENTAGE OF JUST EMERGED FLIES AFTER 24 HOURS OF FEEDING

	Boric acid concentration			
	0.5%	1%	1.5%	2%
Water	12.2 ± 0.58 j	43 ± 0.32 e	54.2 ±0.37 c	63.2 ± 0.37 b
Sugar 5%	18.2 ± 0.37 h	22.4 ± 0.40 h	43.4 ± 0.51 e	69.4 ± 0.51 a
Sugar 10%	15.8 ± 0.37 i	32.6 ± 0.51 g	44.6 ± 0.51 e	47.8 ± 0.66 e
Protein 2.5%	28.0 ± 0.50 g	50.0 ± 0.45 d	53.8 ± 0.58 c	65.0 ± 0.32 a
Protein 5%	31.0 ± 0.45 g	36.2 ± 0.37 f	62.0 ± 0.84 b	67.5±0.51 a

2) Death Percentage after 48 Hours

The results in Table II showed that fly mortality kept rising after 48 hours, reaching a death rate of 99.4%. The same relationship between fly mortality rate and boric acid concentration in the five feeding regimes (water, sugar, or protein solutions) persisted, with a significant difference between the four concentration groups within the five feeding regimes. The water feeding regime of 0.5% boric acid resulted with the least death percentage, followed by 1%, then 1.5%, and 2.0% came with the highest death percentage with means of 40.4, 86.4, 99.6 and 99.4% respectively. For 5% sugar solution regime, 0.5% boric acid resulted with the least death percentage, followed by 1%, then 1.5% and 2.0% with the highest death percentage with means of 54.2, 68.2, 77.4 and 99.4% respectively. For 10% sugar solution regime, 0.5 % boric acid resulted with the least death percentage, followed by 1%, then 1.5%, and 2.0% with the highest death percentage with means of 62.2, 67.6, 82.4 and 94.4%, respectively. For 2.5% protein solution regime 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% with means of 41, 90.4, 90.4 and 94.8% respectively. For 5% protein solution regime, 0.5% boric acid resulted with the least death percentage, followed by 1%, 1.5%, and 2.0% come with means of 70.4, 85.2, 99.2 and 99.4% respectively. The least death percentage resulted with 0.5% boric acid in water feeding regime with a mean of 40.42%, while the highest death percentage resulted with 1.5% boric acid in water and in 5% protein solution and 2% boric acid in water, in 5% sugar solution and 5% protein solution feeding regimes with means of 99.6, 99.2, 99.4, 99.4 and 99.4%, respectively without any significant differences among them. The results show that the feeding regime has some effect on death percentage since there were significant differences between feeding regimes under the same boric acid concentrations, without any noticeable correlation.

TABLE II. DEATH PERCENTAGE OF FLIES AFTER 48 HOURS OF FEEDING

	Boric acid concentration			
	0.5%	1%	1.5%	2%
Water	40.4 ± 0.51 k	86.4 ± 0.51 d	99.4 ± 0.25 a	99.6 ± 0.25 a
Sugar 5%	54.2 ± 0.37 j	68.2 ± 0.37 g	77.4 ± 0.51 f	99.4 ± 0.40 a
Sugar 10%	62.2 ± 0.37 h	67.6 ± 0.51g	82.4 ± 0.51e	94.4 ± 0.51 b
Protein 2.5%	41.0 ± 0.45 k	90.4 ± 0.51 c	90.4 ± 0.40 c	94.8 ± 0.37 b
Protein 5%	70.4 ± 0.51 g	85.2 ± 0.58 d	99.2 ± 0.37 a	99.4 ± 0.40 a

B. Flies at 24 Hours Supplied with Boric Acid Formulations

1) Death Percentage after 24 Hours

The results in Table III show that after 24 hours of the experiment, there was a proportionality between death percentage and concentration of boric acid in all feeding regimes. For the water feeding regime, the death percentage means were 70.8, 73.2, 85.6, and 90.4 for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 5% sugar solution regime, the death percentage means were 53.4, 67.8, 7.2, and 83.4% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 10% sugar solution regime, the death percentage means were 43.4, 53, 65.2, and 73.2% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 2.5 % protein solution regime, the death percentage means were 43.2, 50.2, 63, and 74.2% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 5% protein solution regime, the death percentage means were 32.6, 48.2, 70.2, and 75.8% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. The lowest death percentage was observed with 0.5% boric acid in the 5% protein feeding regime (32.6%), while the highest death percentages were observed with 2% boric acid in the water feeding regime (90.4%). The results show that the feeding regime has some effect on death percentage since there were significant differences between feeding regimes under the same boric acid concentrations, without any noticeable correlation.

TABLE III. DEATH PERCENTAGE OF 24 HOURS AGED-FLIES AFTER 24 HOURS OF FEEDING

	Boric acid concentration			
	0.5%	1%	1.5%	2%
Water	70.8 ± 0.66 d	73.2 ± 0.37 c	85.6 ± 0.68 b	90.4 ± 0.51 a
Sugar 5%	53.4 ± 0.51 f	67.8 ± 0.37 d	77.2 ± 0.74 c	83.4 ± 0.25 b
Sugar 10%	43.4 ± 0.51 g	53.0 ± 0.55 f	65.2 ± 0.66 e	73.2 ± 0.80 c
Protein 2.5 %	43.2 ± 0.49 g	50.2 ± 0.66 f	63.0 ± 0.84 e	74.2 ± 0.37 c
Protein 5 %	32.6 ± 0.51 h	48.2 ± 0.37 f	70.2 ± 0.66 d	± 0.37 c

TABLE IV. DEATH PERCENTAGE OF FLIES AFTER 48 HOURS OF FEEDING

	Boric acid concentration			
	0.5%	1%	1.5%	2%
Water	88.2 ± 0.37 b	95.6 ± 0.25 a	97.0 ± 0.32 a	99.6 ± 0.25 a
Sugar 5%	82.2 ± 0.66 c	92.4 ± 0.43 b	94.6 ± 0.4 a	97.0 ± 0.32 a
Sugar 10%	90.8 ± 0.37 b	96.8 ± 0..37 a	98.2 ± 0.37 a	99.4 ± 0.4 a
Protein 2.5%	77.0 ± 0.55 d	80.8 ± 0.37 c	99.2 ± 0.37 a	99.8 ± 0.2 a
Protein 5%	65.0 ± 0.55 e	75.8 ± 0.37 d	99.4 ± 0.24 a	± 0.58 a

2) Death Percentage after 48 Hours

Table IV shows a respective proportionality for the results after 48 hours between the death percentage and boric acid concentrations in the five feeding regimes. For the water feeding regime, the death percentage means were 88.2, 95.6, 97, and 99.6% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 5% sugar solution regime, the death percentage means were 82.2, 92.4, 94.6, and 97% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 10% sugar solution regime, the death percentage means were 90.8, 96.8, 98.2, and 99.4% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 2.5% protein solution regime, the death percentage means were 77, 80.8, 99.2, and 99.8% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. For the 5% protein solution regime, the death percentage means were 65, 75.8, 99.4, and 99.2% for 0.5, 1, 1.5, and 2.0% boric acid, respectively. The lowest death percentage was observed with 0.5% boric acid in the 5% protein feeding regime (65.0%), while most treatments had a high death percentage (above 95%) without significant differences. The results show that the feeding regime has some effect on death percentage since there were significant differences between feeding regimes under the same boric acid concentrations, without any noticeable correlation.

IV. DISCUSSION

The Mediterranean fruit fly *Ceratitis capitata* causes enormous damage to fruit transport and conservation. At present, the main method of controlling this fruit fly is chemical control [34]. However, the long-term use of insecticides makes the resistance of *Ceratitis capitata* stronger [35-36]. Long employed as an insecticide in urban pest management, boric acid dust has been shown to be a successful alternative for application [37]. However, dust formulations are difficult to apply and require specialized equipment. This study aimed to evaluate the efficacy of liquid baits containing boric acid for the control of *Ceratitis capitata in* fruit transport and conservation. Toxic sugar and protein baits were prepared using boric acid at different concentrations, from 0.5 to 2%. Because it has been used in past tests on harmful sugar baits and is secure and environmentally friendly, boric acid was chosen [26]. In this study, no significant differences were observed in the rate of insect deaths between baits containing water, sugar, or proteins. However, differences were observed according to insect ages with a maximum death rate of 67.5% for just-emerged flies after 24 hours and 99.8% after 48 hours of feeding. The relationship between insect age and mortality was also studied in [38-39]. The application of ATSBs can increase the average mortality of the Mediterranean fruit fly *Ceratitis capitata* by up to 99.6%, by increasing attraction and not toxicity. The results of this study were similar to [40], which reported that the death rate of resistant *Aedes aegypti* mosquitoes in toxic sugar baits was 90.8%. In [41], the attractive toxic baits treatment containing 1% of boric acid decreased the number of mosquitos substantially. Male mosquitos were decreased by 93%, while female mosquitos were reduced by 90%. These results were also supported by many other studies [34, 42-43].

To prevent the spread of fruit diseases, novel techniques that use automated detection can offer very useful tools to detect pest damage [44-46]. In [46], an innovative method was presented to automate the detection of damage caused by a devastating tomato pest, known as *Tuta absoluta.* Biocontrol using plant extracts can also improve fruit and seed storage and protection [47].

V. CONCLUSION

This study showed that baits containing boric acid are effective in controlling the Mediterranean fruit fly *Ceratitis capitata*, as they can increase their death rate to 99.8%. The death rate is positively correlated with the increase in boric acid concentration (from 0.5 to 2%). The baits containing boric acid with sugar or proteins have no significant differences with an aqueous solution, and thus nutrients can be applied to make baits more attractive to pests without influencing death rates. On the other hand, applying boric acid baits for 48 hours gave better fly death rates than for 24 hours. However, as the consumption of different boric acid formulations increased, the death percentage increased as the starvation period prolonged. It is strongly recommended to use boric acid for the control of medflies by trapping or any effective technique that ensures no direct contact between the host plant and the boric acid formulation. The application of mixed boric acid baits is an effective and environmentally friendly alternative way of controlling *Ceratitis capitata*. Knowing which compounds or characteristics of the bait make it more palatable for the species to be controlled will result in higher bait consumption and effectiveness. Boric acid appears to be an excellent candidate for pest control baiting systems. Its solubility and stability in water, low mammalian toxicity, low cost, and no evidence of resistance to it in any insect species make it a particularly appealing candidate.

REFERENCES

[1] N. G. Ravichandra, "Horticulture and Its Role in the National Economies," in *Horticultural Nematology*, N. G. Ravichandra, Ed. New Delhi: Springer India, 2014.

[2] G. Salerno, M. Rebora, S. Piersanti, E. Gorb, and S. Gorb, "Mechanical ecology of fruit-insect interaction in the adult Mediterranean fruit fly Ceratitis capitata (Diptera: Tephritidae)," *Zoology*, vol. 139, Apr. 2020, Art. no. 125748, https://doi.org/10.1016/j.zool.2020.125748.

[3] M. Sarwar, "Quarantine Treatments for Mortality of Eggs and Larvae of Fruit Flies (Diptera: Tephritidae) Invading Fresh Horticulture Perishable Produces," *International Journal of Animal Biology*, vol. 1, no. 5, pp. 196–201, Jul. 2023.

[4] A. J. Allwood and R. A. I. Drew, "Management of fruit flies in the Pacific. A regional symposium, Nadi, Fiji 28-31 October 1996.," in *Management of fruit flies in the Pacific. A regional symposium*, Nadi, Fiji, Oct. 1996.

[5] H. J. Rafalimanana and R. B. Randriatsaramiafara, "Effect of abiotic parameters on fruit flies behavior (*Diptera: Tephritidae*) in citrus orchards at Ambohijafy," *Acta Horticulturae*, no. 1267, pp. 7–12, Jan. 2020, https://doi.org/10.17660/ActaHortic.2020.1267.2.

[6] E. Suday and M. K. Billah, A field guide to the management of economically important tephritid fruit flies in Africa. Nairobi, Kenya: ICIPE Science Press, 2006.

[7] I. M. White and M. M. Elson-Harris, *Fruit flies of economic significance: their identification and bionomics.* Wallingford, UK: CAB International, 1992.

[8] N. J. Liquido, R. T. Cunningham, and S. Nakagawa, "Host Plants of Mediterranean Fruit Fly (Diptera: Tephritidae) on the Island of Hawaii (1949-1985 Survey)," *Journal of Economic Entomology*, vol. 83, no. 5, pp. 1863–1878, Oct. 1990, https://doi.org/10.1093/jee/83.5.1863.

[9] V. Navarro-Llopis, S. Vacas, J. Sanchis, J. Primo, and C. Alfaro, "Chemosterilant Bait Stations Coupled With Sterile Insect Technique: An Integrated Strategy to Control the Mediterranean Fruit Fly (Diptera: Tephritidae)," *Journal of Economic Entomology*, vol. 104, no. 5, pp. 1647–1655, Oct. 2011, https://doi.org/10.1603/EC10448.

[10] M. A. Légaré, C. Pranckevicius, and H. Braunschweig, "Metallomimetic Chemistry of Boron," *Chemical Reviews*, vol. 119, no. 14, pp. 8231–8261, Jul. 2019, https://doi.org/10.1021/acs.chemrev.8b00561.

[11] S. Bolan *et al.*, "Boron contamination and its risk management in terrestrial and aquatic environmental settings," *Science of The Total Environment*, vol. 894, Oct. 2023, Art. no. 164744, https://doi.org/ 10.1016/j.scitotenv.2023.164744.

[12] W. Quarles, "Boric acid, borates and household pests," *The IPM Practioner*, vol. 23, no. 3, pp. 1–12, 2001.

[13] F. H. Nielsen, "Boron in human and animal nutrition," *Plant and Soil*, vol. 193, no. 1, pp. 199–208, Jun. 1997, https://doi.org/10.1023/ A:1004276311956.

[14] T. A. Abdel-Hafeez, S. M. Elmahdy, and Y. E. Afia, "Using Boric Acid as a Safety Insecticide for Controlling Peach Fruit Fly, Bactrocera zonata, Saunders (Diptera: Tephritidae)," *Journal of Plant Protection*

and Pathology, vol. 11, no. 5, pp. 253–257, May 2020, https://doi.org/10.21608/jppp.2020.103572.

[15] W. Quarles, "Borates provide least-toxic wood protection," *IPM practitioner*, vol. 10, no. 4, 1992.

[16] C. Flox *et al.*, "Degradation of 4,6-dinitro-o-cresol from water by anodic oxidation with a boron-doped diamond electrode," *Electrochimica Acta*, vol. 50, no. 18, pp. 3685–3692, Jun. 2005, https://doi.org/10.1016/j.electacta.2005.01.015.

[17] W. G. Woods, "An introduction to boron: history, sources, uses, and chemistry.," *Environmental Health Perspectives*, vol. 102, no. suppl. 7, pp. 5–11, Nov. 1994, https://doi.org/10.1289/ehp.94102s75.

[18] E. F. S. Authority (EFSA), "Opinion of the Scientific Panel on Dietetic products, nutrition and allergies [NDA] on a request from the Commission relating to the evaluation of allergenic foods for labelling purposes," *EFSA Journal*, vol. 2, no. 3, 2004, https://doi.org/10.2903/j.efsa.2004.32.

[19] D. G. Cochran, "Toxic effects of boric acid on the German cockroach," *Experientia*, vol. 51, no. 6, pp. 561–563, Jun. 1995, https://doi.org/10.1007/BF02128743.

[20] G. C. Müller and Y. Schlein, "Efficacy of toxic sugar baits against adult cistern-dwelling Anopheles claviger," *Transactions of The Royal Society of Tropical Medicine and Hygiene*, vol. 102, no. 5, pp. 480–484, May 2008, https://doi.org/10.1016/j.trstmh.2008.01.008.

[21] R. D. Xue and D. R. Barnard, "Boric Acid Bait Kills Adult Mosquitoes (Diptera: Culicidae)," *Journal of Economic Entomology*, vol. 96, no. 5, pp. 1559–1562, Oct. 2003, https://doi.org/10.1093/jee/96.5.1559.

[22] R. Xue, G. C. Müller, D. L. Kline, and D. R. Barnard, "Effect of Application Rate and Persistence of Boric Acid Sugar Baits Applied to Plants for Control of Aedes albopictus," *Journal of the American Mosquito Control Association*, vol. 27, no. 1, pp. 56–60, Mar. 2011, https://doi.org/10.2987/10-6069.1.

[23] J. C. Beier, G. C. Müller, W. Gu, K. L. Arheart, and Y. Schlein, "Attractive toxic sugar bait (ATSB) methods decimate populations of Anopheles malaria vectors in arid environments regardless of the local availability of favoured sugar-source blossoms," *Malaria Journal*, vol. 11, no. 1, Feb. 2012, Art. no. 31, https://doi.org/10.1186/1475-2875-11-31.

[24] R. D. Xue *et al.*, "Attractive targeted sugar baits: Field evaluations and potential use in mosquito control," *Wing Beats*, vol. 24, pp. 13–18, 2013.

[25] W. A. Qualls, R. Xue, E. E. Revay, S. A. Allan, and G. C. Müller, "Implications for operational control of adult mosquito production in cisterns and wells in St. Augustine, FL using attractive sugar baits," *Acta Tropica*, vol. 124, no. 2, pp. 158–161, Nov. 2012, https://doi.org/10.1016/j.actatropica.2012.07.004.

[26] D. P. Naranjo *et al.*, "Evaluation of boric acid sugar baits against Aedes albopictus (Diptera: Culicidae) in tropical environments," *Parasitology Research*, vol. 112, no. 4, pp. 1583–1587, Apr. 2013, https://doi.org/10.1007/s00436-013-3312-8.

[27] T. A. Devirian and S. L. Volpe, "The Physiological Effects of Dietary Boron," *Critical Reviews in Food Science and Nutrition*, vol. 43, no. 2, pp. 219–231, Mar. 2003, https://doi.org/10.1080/10408690390826491.

[28] R. O. Nable, G. S. Bañuelos, and J. G. Paull, "Boron toxicity," *Plant and Soil*, vol. 193, no. 1, pp. 181–198, Jun. 1997, https://doi.org/10.1023/A:1004272227886.

[29] R. J. Reid, "Boron Toxicity and Tolerance in Crop Plants," in *Crop Improvement Under Adverse Conditions*, N. Tuteja and S. S. Gill, Eds. New York, NY: Springer, 2013, pp. 333–346.

[30] C. L. Ogg and R. E. Gold, "Inclusion of Insecticidal Bait Stations in a German Cockroach (Orthoptera: Blattellidae) Control Program," *Journal of Economic Entomology*, vol. 86, no. 1, pp. 61–65, Feb. 1993, https://doi.org/10.1093/jee/86.1.61.

[31] M. Will and D. Guenther, *Food Quality and Safety Standards*, 2nd ed. Eschborn, Germany: Deutsche Gesellschaft fuer, 2007.

[32] B. Le, H. Park, K. Campbell, M. K. Rust, C.-Y. Lee, and D.-H. Choe, "Laboratory evaluations of biodegradable boric acid hydrogel baits for the control of Argentine ant (Hymenoptera: Formicidae)," *Journal of Economic Entomology*, vol. 116, no. 2, pp. 643–647, Apr. 2023, https://doi.org/10.1093/jee/toad037.

[33] G. Kumar, A. Sharma, and R. C. Dhiman, "Laboratory evaluation of the efficacy of boric acid containing toxic sugar baits against Anopheles culicifacies, An. stephensi and Aedes aegypti mosquitoes," *Journal of Vector Borne Diseases*, vol. 59, no. 1, pp. 52-56, Mar. 2022, https://doi.org/10.4103/0972-9062.331414.

[34] Z. Y. Gu *et al.*, "Efficacy of orally toxic sugar baits against contact-insecticide resistant culex quinquefasciatus," *Acta Tropica*, vol. 202, Art. no. 105256, Feb. 2020, https://doi.org/10.1016/j.actatropica.2019.105256.

[35] A. Guillem-Amat, L. Sánchez, E. López-Errasquín, E. Ureña, P. Hernández-Crespo, and F. Ortego, "Field detection and predicted evolution of spinosad resistance in Ceratitis capitata," *Pest Management Science*, vol. 76, no. 11, pp. 3702–3710, 2020, https://doi.org/10.1002/ps.5919.

[36] S. Elfekih, M. Shannon, J. Haran, and A. P. Vogler, "Detection of the Acetylcholinesterase Insecticide Resistance Mutation (G328A) in Natural Populations of Ceratitis capitata," *Journal of Economic Entomology*, vol. 107, no. 5, pp. 1965–1968, Oct. 2014, https://doi.org/10.1603/EC14166.

[37] J. C. Gore, L. Zurek, R. G. Santangelo, S. M. Stringham, D. W. Watson, and C. Schal, "Water Solutions of Boric Acid and Sugar for Management of German Cockroach Populations in Livestock Production Systems," *Journal of Economic Entomology*, vol. 97, no. 2, pp. 715–720, Apr. 2004, https://doi.org/10.1093/jee/97.2.715.

[38] D. Habes, K. Bouazdia, R. Messiad, A. Boussatha, and N. Soltani, "Bioactivity of Injected Boric Acid on German Cockroaches: Lethality, Analysis of Residues and Acethylcholinesterase and Glutathione S-Transferase Activities," *European Journal of Scientific Research*, vol. 103, no. 2, pp. 256–266, Jun. 2013.

[39] S. Tine, N. Aribi, and N. Soltani, "Laboratory evaluation of azadirachtin against the oriental cockroach, Blatta orientalis L. (Dictyoptera, Blattellidae): Insecticidal activity and reproductive effects," *African Journal of Biotechnology*, vol. 10, no. 85, pp. 19816–19824, 2011, https://doi.org/10.4314/ajb.v10i85.

[40] M. A. Pearson *et al.*, "Evaluation of boric acid as toxic sugar bait against resistant Aedes aegypti mosquitoes," *Journal of Vector Ecology*, vol. 45, no. 1, pp. 100–103, 2020, https://doi.org/10.1111/jvec.12377.

[41] W. A. Qualls *et al.*, "Indoor use of attractive toxic sugar bait (ATSB) to effectively control malaria vectors in Mali, West Africa," *Malaria Journal*, vol. 14, no. 1, Aug. 2015, Art. no. 301, https://doi.org/10.1186/s12936-015-0819-8.

[42] Z. P. Stewart, R. M. Oxborough, P. K. Tungu, M. J. Kirby, M. W. Rowland, and S. R. Irish, "Indoor Application of Attractive Toxic Sugar Bait (ATSB) in Combination with Mosquito Nets for Control of Pyrethroid-Resistant Mosquitoes," *PLOS ONE*, vol. 8, no. 12, 2013, Art. no. e84168, https://doi.org/10.1371/journal.pone.0084168.

[43] J. E. C. Furnival-Adams *et al.*, "Indoor use of attractive toxic sugar bait in combination with long-lasting insecticidal net against pyrethroid-resistant Anopheles gambiae: an experimental hut trial in Mbé, central Côte d'Ivoire," *Malaria Journal*, vol. 19, no. 1, Jan. 2020, Art. no. 11, https://doi.org/10.1186/s12936-019-3095-1.

[44] N. C. Eli-Chukwu, "Applications of Artificial Intelligence in Agriculture: A Review," *Engineering, Technology & Applied Science Research*, vol. 9, no. 4, pp. 4377–4383, Aug. 2019, https://doi.org/10.48084/etasr.2756.

[45] S. Alqethami, B. Almtanni, W. Alzhrani, and M. Alghamdi, "Disease Detection in Apple Leaves Using Image Processing Techniques," *Engineering, Technology & Applied Science Research*, vol. 12, no. 2, pp. 8335–8341, Apr. 2022, https://doi.org/10.48084/etasr.4721.

[46] L. Loyani and D. Machuve, "A Deep Learning-based Mobile Application for Segmenting Tuta Absoluta's Damage on Tomato Plants," *Engineering, Technology & Applied Science Research*, vol. 11, no. 5, pp. 7730–7737, Oct. 2021, https://doi.org/10.48084/etasr.4355.

[47] M. Pirzadeh and M. Aminlari, "Effects on the Physiochemical Properties of Stored Pomegranate Seeds by the Application of Aloe Vera Gel as Coating Agent," *Engineering, Technology & Applied Science Research*, vol. 9, no. 4, pp. 4543–4547, Aug. 2019, https://doi.org/10.48084/etasr.2949.