● PESTICIDE FACTSHEET

BORIC ACID AND BORATES

Boric acid and borates are naturally occurring compounds containing the element boron. They are widespread and abundant in soil, water, and food. They are often recommended as least-toxic pesticides for killing insects, mites, algae, fungi, and higher plants. Examples of pests for which boric acid and borates are commonly used include fleas, termites, cockroaches, wood-boring insects, and wood decay fungi.

Boric acid and its chemical relatives kill insects by acting as a stomach poison and by absorbing the waxes that protect insects from drying out. They also stop fungi from producing spores and stop photosynthesis (using light to produce sugars) in plants.

Symptoms of exposure to boric acid used as a pesticide include difficult breathing, headache, lethargy, nausea, coughing, and wheezing.

The most significant health concerns associated with exposure to boric acid and borates are their ability to reduce successful reproduction. In laboratory tests, boric acid has damaged sperm, increased the frequency of prenatal mortality (miscarriages), reduced birth weight, and caused a variety of birth defects. In general, these effects occurred during relatively high exposures to boric acid.

Fish need boron in order to develop and grow normally. However, high concentrations (over 100 parts per million) can be toxic.

When using boric acid and its chemical relatives as least-toxic pesticides, the goal should be to use application methods and techniques that do not significantly increase exposure to these widespread compounds above the levels that occur naturally. For example, judicious use of boric acid insecticide baits minimizes exposure to pets, people, and the environment.

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Boric acid and its chemical relatives are pesticides that are derived from the element boron. Boron rarely occurs alone and is typically found in combination with other elements; common combinations are boric acid or borates.[1] Unlike many pesticides which are synthetic compounds,[2] boric acid and related pesticides are naturally occurring compounds.[1]

Boron compounds are widely found in rivers, streams, oceans, groundwater, and soil.[3,4] The U.S. Environmental Protection Agency (EPA) calls them "ubiquitous in the environment."[3]

Boron is also an essential nutrient for plants,[3] and is therefore found in many of the foods we eat.[4] Researchers estimate that people consume between 10 and 25 milligrams of boron in their food each day.[4]

Borates are used in a wide variety of consumer products: laundry detergents, bleaches,[5] makeup, skin and hair care products, shaving creams, and some medicines.[4]

Boric acid and related compounds have been used as pesticides for decades: they were first registered for use in the U.S. in 1948.[6]

Least-toxic Pesticides?

Partly because they are widespread, naturally occurring compounds, boric acid and borates are often recommended as part of a least-toxic pest management strategy. (For examples, see references 7 and 8.)

Boric acid and borates have some advantages as pesticides. They have less human toxicity than some other pesticides, and fewer insects have developed resistance to them. Certain insecticides actually repel insects; this is not the case with boric acid so it can be successfully used in bait products.[5]

However, boric acid and its chemical relatives can pose hazards. For example, the University of Nebraska-Lincoln Cooperative Extension describes boric acid this way: "Although boric acid is relatively safe to humans and other mammals, it can be harmful if accidentally ingested and must be kept away from food, children and pets. Care must be taken not to breathe in the dust when you apply it. Like other dust formulations, it should be used in places where it will not move around."[8]

This article summarizes the health and environmental hazards associated with boric acid and borates, along with some discussion of the reasons that boric acid may pose fewer hazards than other insecticides.

Chemical Group

Seven boric acid and borate compounds are registered as pesticides in the U.S.[9] For the names and chemical

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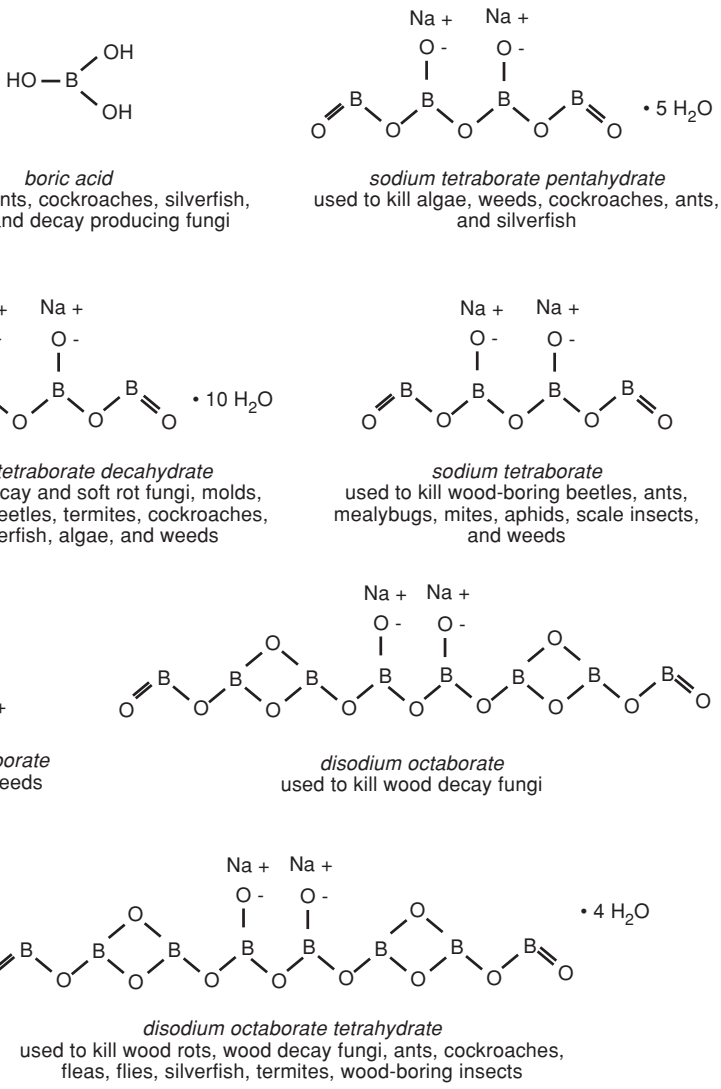
Figure 1
Boric Acid and Borates



structures of these seven compounds, see Figure 1.

According to EPA, "the toxicity of all these boron related chemicals is expected to be similar."[9]

Uses

Boric acid and borates are used to kill an extraordinary variety of pests: insects, mites, algae, fungi, and higher plants.[9] Commonly, they are used to kill ants, fleas, termites, cockroaches, wood-boring insects, and wood decay fungi.[10] Sodium metaborate is used only as an herbicide, and disodium octaborate is used only for wood treatment. The other compounds have multiple uses.[9] (See Figure 1.)

Mode of Action

Boric acid and borates kill different types of organisms in different ways. Insects are killed by boric acid because it acts as a stomach poison and also as an abrasive on the outer surface of the insects.[9] Boric acid also absorbs waxes from the outer surface of the insects, causing them to dry out and die.[2] In fungi, borates stop the production of spores so that the fungus cannot reproduce. Plants are killed when boric acid dessicates the plant, and borates interrupt photosynthesis, the process by which plants use light to produce sugars.[9]

Inert Ingredients

Like most pesticides, commercial boric acid and borate products contain ingredients which, according to U.S. pesticide law, are called "inert."[11] There is very little publicly available information about the identity of the inert ingredients in boric acid and borate products. These ingredients were not included in most of the laboratory studies summarized in the rest of this article.

Symptoms of Exposure

Symptoms reported by people exposed to boric acid used as an insecticide include itching skin, difficult breathing, headache, tingling lips, lethargy, nausea, coughing, wheezing, hoarseness, and vomiting.[12]

Based primarily on studies of people exposed to borax (sodium tetraborate decahydrate) at work, the Agency for Toxic Substances and Disease Registry concluded that "irritation of the nose and throat or eyes can occur if small amounts of boron are breathed in."[13]

According to the National Institute for Occupational Safety and Health, sodium tetraborate pentahydrate is a severe eye irritant.[14]

Effects on Sperm

Boric acid's ability to disrupt sperm production was first documented in the early 1970s.[15] Since then, a series of studies have confirmed these effects, and provided additional details.

The effect that occurs at the relatively low boric acid exposures is a reduction in the number of sperm that are capable of moving. Studies conducted by the National Institute for Environmental Health Sciences's National Toxicology Program[16-18] showed that sperm from rats and mice fed boric acid was more likely to be incapable of moving[19] than sperm from unexposed animals. This inability to move occurred at all dose levels tested

in these studies.[16-18] (See Figure 2.)

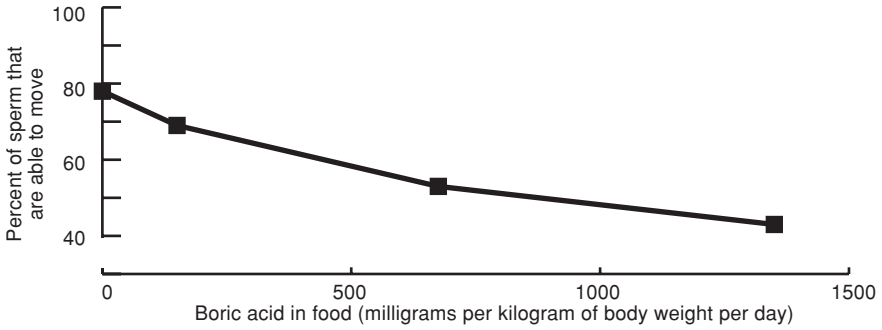
At higher exposure levels, boric acid inhibits the release of sperm from the testes. The same group of researchers mentioned in the previous paragraph found that an intermediate exposure to boric acid inhibited sperm release[19] in rats.[16,20] This effect occurred at all but the lowest dose level tested in their experiments.[16,20]

At even higher exposure levels, boric acid causes atrophy of the testes. National Institute for Environmental Health Sciences researchers demonstrated that atrophy caused by boric acid exposure occurs in both rats and mice.[16,20,21] The atrophy continues even after exposure ends.[16,20] One study found no sperm production for up to 32 weeks after exposure.[16]

National Toxicology Program scientists investigated how boric acid causes testes to atrophy, and concluded that boric acid inhibits the formation of DNA (genetic material) in sperm cells.[22]

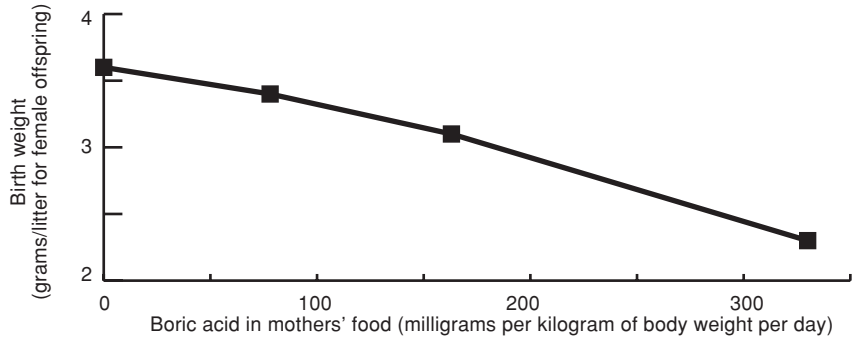
Relatively high levels of exposure to boric acid also have another effect on sperm. EPA researchers showed that laboratory animals fed boric acid produced sperm that swam more slowly than that of unexposed animals. Swimming speed was reduced about 30 percent by a single dose of boric acid.[23]

Figure 2
Effect on Sperm Movement



Source: Chapin, R.E. and W.W. Ku. 1994. The reproductive toxicity of boric acid. *Environ. Health Persp.* 102(Suppl. 7):87-91.

Figure 3
Effect on Birth Weight



Source: Heindel, J.J. et al. 1992. Developmental toxicity of boric acid in mice and rats. *Fund. Appl. Toxicol.* 18:266-277.

Boric acid reduces the ability of sperm to move and also reduces birth weight. Both these effects occurred at all dose levels tested in laboratory studies.

Effects on Pregnancy Success

Boric acid reduced pregnancy success in laboratory studies with mice, rats, and rabbits conducted by the National Toxicology Program and other researchers affiliated with a boric acid manufacturer. In all three animals, feeding of boric acid during pregnancy caused an increase in prenatal mortality (miscarriages); the increases occurred at the highest dose level tested in each experiment.[24-26]

Boric acid has also reduced pregnancy success in studies lasting several generations. In a different National Toxicology Program study, mice were fed boric acid for two generations. The number of litters produced by exposed pairs was less than the number produced by unexposed pairs. The reduction was over 50 percent at the middle dose level tested in this experiment, and the high dose pairs produced no litters.[27]

A three generation study of rats, conducted as part of the registration process, showed that the reduction in the number of litters produced occurred when only the mother was fed borax. The decrease occurred at the highest dose level tested in this experiment.[28]

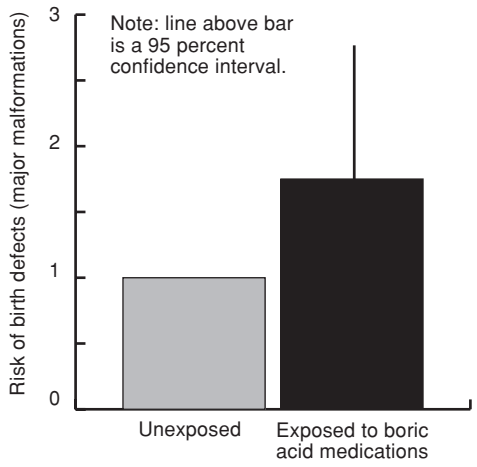
Effects on Birth Weight

Offspring born to animals exposed to boric acid during pregnancy weigh less than the offspring of unexposed mothers. In National Toxicology Program studies, birth weights of offspring from exposed mothers weighed between 6 and 50 percent less than the offspring of unexposed animals.[24,26] In one of the studies, the decrease in birth weights occurred at all dose levels tested.[24] (See Figure 3.)

Birth Defects

Boric acid has caused a variety of birth defects in tests conducted by the

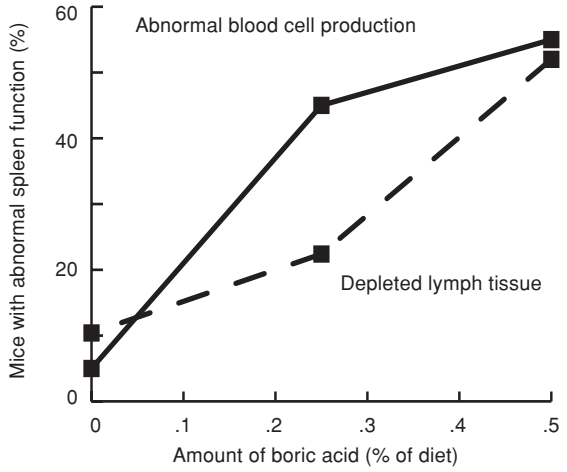
Figure 4
Birth Defects and Use of Boric Acid Medications



Source: Heinonen, O.P, D. Slone, and S. Shapiro. 1977. *Birth defects and drugs in pregnancy.* Chap. 21. Antimicrobial and antiparasitic agents. Littleton MA: Publishing Sciences Group, Inc.

Use of boric acid as a medicine during pregnancy has been linked with an increased risk of birth defects.

Figure 5
Effects on the Spleen



Source: Dieter, M.P. 1994. Toxicity and carcinogenicity studies of boric acid in male and female B6C3F1 mice. *Environ. Health Persp.* 102(Suppl 7):93-97.

Boric acid can disrupt the normal functions of the spleen, an organ important in filtering and storing blood.

National Toxicology Program and EPA. These defects include heart defects, brain malformations, abnormal ribs, and missing vertebrae. In these studies researchers fed laboratory animals boric acid during all or part of their pregnancies. The increase in birth defects occurred at both the middle and the high dose level tested in experiments with mice and rats, and at the high dose level in experiments with rabbits.[24-26,29]

Research about the association between boric acid exposure and birth defects illustrates the complexities in the ways that pesticides disrupt normal development. EPA toxicologists showed that boric acid exposure on the ninth and tenth day of pregnancy (in rats) caused offspring to develop with six instead of seven vertebrae (spinal column segments[19]) in their necks.[30] Toxicologists at North Carolina State University showed that boric acid exposure (in mice) just one day earlier, on the eighth day of pregnancy, caused a rib to fail to develop.[31] Scientists were also able to identify the family of genes that is affected by boric acid and causes the missing vertebrae.[32]

One study indicates that the increase in birth defects caused by boric acid exposure in laboratory studies also occurs in people. In the 1970s, Boston University Medical Center physicians found that mothers who used boric acid medications during pregnancy were almost twice as likely to give birth to children with a "major malformation" than mothers who did not use these medications.[33] (See Figure 4.)

Ability to Cause Cancer (Carcinogenicity)

EPA has classified boric acid in "Group E." This means that the agency has evaluated laboratory tests of boric acid's carcinogenicity and they show no evidence that the compound causes cancer.[34]

Effects on Blood and the Spleen

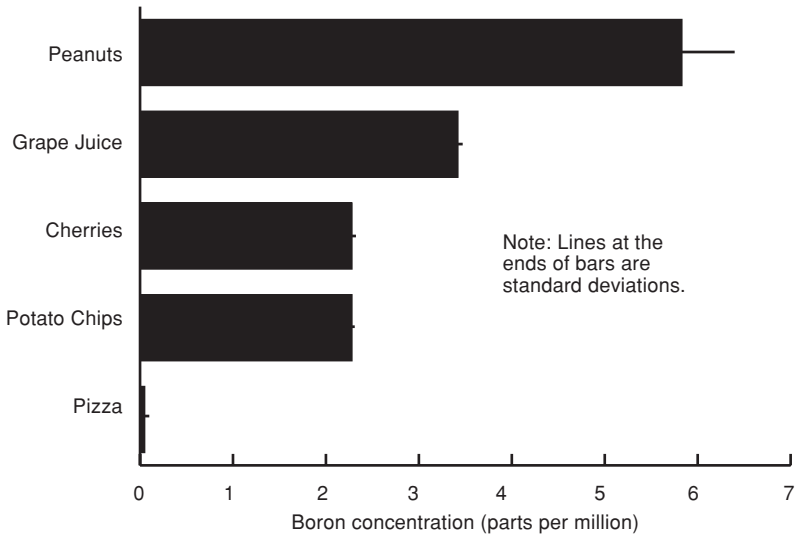
Borax (sodium tetraborate decahydrate) causes anemia,[35] a condition in which blood is deficient in the oxygen-carrying molecule called hemoglobin.[19] In a study of dogs submitted to EPA by a borate manufacturer as part of the pesticide registration process, dogs who were fed borax for three months had less hemoglobin in their blood than unexposed dogs. This anemia occurred at the high dose level tested in this experiment.[35]

Boric acid also affects the production of blood cells. Research at the National Institute of Environmental Health Sciences found that mice fed boric aid for three months produced blood cells in the spleen,[36] although this production normally takes place in the bone marrow.[19] In addition, lymph tissue[19] was depleted in the spleens of mice fed boric acid for two years.[36] These effects occurred at all dose levels tested in these experiments.[36] (See Figure 5.)

Effects on Hormones

Hormones are chemical messengers that regulate all biological processes in the body, including growth, development, and metabolism. In recent years, scientists have developed evidence that certain chemicals, including pesticides, disrupt the normal functioning of hormone systems.[37]

Figure 6
Naturally Occurring Boron Levels in Common Foods



Source: Hunt, C.D. and S.L. Meacham. 2001. Aluminum, boron, calcium, copper, iron, magnesium, manganese, molybdenum, phosphorus, potassium, sodium, and zinc: concentrations in common western foods and estimated daily intakes by infants; toddlers; and male and female adolescents, adults, and seniors in the United States. *J. Am. Diet. Assoc.* 101:1058-60. See Table 1.

A wide variety of common foods contain boron.

Two studies indicate that boric acid may have these kinds of effects on hormones. In research done by the National Toxicology Program, rats fed boric acid for four days had lower blood testosterone levels than unexposed rats.[38] (Testosterone is a male sex hormone.[19]) North Carolina State University animal scientists showed that feeding boric acid to pigs lowered blood concentrations of two thyroid hormones.[39]

Effects on the Nervous System

Neurological effects (headache, tremors, restlessness, and convulsions) have occurred in newborn infants who accidentally ingested large amounts of boric acid. According to the Agency for Toxic Substances and Disease Registry, studies evaluating whether boric acid can cause effects on the nervous system have been limited to studies of exposures for a short time at high dose levels; whether or not effects occur following long-term exposure at lower doses is not known.[40]

Occurrence in Food

Boron occurs naturally in many foods, particularly in fruits and vegetables. (See Figure 6 for some examples.) A few foods have quite high concentrations: pears and strawberries can have about 160 parts per million (ppm) boron and red cabbage can have up to 300 ppm. EPA estimates that pesticide uses of boric acid add 1 ppm to the naturally occurring amount.[41]

Occurrence in Water

According to the Agency for Toxic Substances and Disease Registry, boron is "widely distributed in water."[42] One national survey found boron in 98 percent of the samples analyzed, with concentrations varying from 1 part per billion (ppb) to 5 ppm. Most of this boron comes from natural weathering of rocks that contain boron.[42]

Effects on Fish

Boron is an essential nutrient for fish. This means that if the boron concentration in water is too low, fish will not thrive. For example, University of California researchers found that if juvenile rainbow trout were kept in water with a boron concentration less than about 100 ppb, their growth was reduced. If developing zebrafish eggs were kept in water with a boron concentration less than 2 ppb, mortality was high; over 80 percent died in three days.[43]

However, high concentrations of boron are toxic to fish. In the University of California study, death of developing rainbow trout and zebrafish occurred if concentrations were greater than 100 ppm.[43]

In a laboratory study conducted by researchers at EA Engineering, Science, and Technology, Inc., Proctor and Gamble, and the University of Kentucky, boric acid at relatively low concentrations (10 ppb) in distilled water caused birth defects in developing rainbow trout.[44] However, this low boron concentration did not cause birth defects when these experiments were repeated using stream water.[44] Many wild trout streams have naturally occurring boron levels in this range.[43]

Effects on Frogs

Frogs can be harmed by high concentrations of boric acid. Zoologists from the Stover Group, Oklahoma State University, and the U.S. Army showed that boric acid caused death of egg-forming cells in female frogs at concentrations of 50 ppm. A higher concentration (100 ppm) caused abnormal development of fertilized eggs and reduced the number of viable offspring. Sperm counts in male frogs were reduced by 500 ppm of boric acid; the same concentration increased the occurrence of abnormal sperm.[45]

Effects on Birds

Birds can also be harmed by relatively high levels of exposure to boric acid. Poultry scientists from the University of Georgia showed that exposure of chicks to boric acid reduced

their growth and caused the development of abnormal curled feathers. These effects were caused by exposure to boric acid from both treated litter and treated food.[46]

Effects on Plants

Small amounts of boron are needed by all plants; it is "one of the more essential elements for plant growth."[5] High concentrations, however, are toxic. This toxicity is what allows boric acid and borates to be used as herbicides.[5,9]

Symptoms of boron toxicity in plants include leaf burn, dead areas inside fruits, dead areas of bark, and dieback of stems.[47]

Persistence

Unlike pesticides composed of complex molecules, boric acid and borates do not break down. There is "no information available"[48] suggesting that boron compounds are degraded in air. In water, "boron compounds rapidly transform to borates, the naturally occurring form of boron. No further degradation is possible."[48] In soil, borates "are not further degraded...."[48]

Conclusion

Boric acid and borates, unlike most pesticides, are common naturally occurring compounds. Like most pesticides, however, they can cause health problems. Laboratory studies have identified a variety of health effects caused by exposure to these compounds, particularly at high doses. Probably the most striking of these is their ability to disrupt reproduction and development.

At the same time, boron is an essential nutrient for many living things. Evidence is accumulating that it is also important for people, and is used by our bodies in a variety of ways.[49]

Judicious use of boric acid and its chemical relatives as least-toxic pesticides requires application methods and techniques that do not significantly increase exposure to these widespread compounds above the levels that occur naturally. For example, baits, applications inside enclosed areas like wall voids, and injection treatments for wood minimize unwanted exposure.

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