what's really in your insect repellent

Deet. Picaridin. Oil of lemon eucalyptus. What are these things anyway? Where do they come from? Which work best and which are safe? Here's what we've found after years of testing and hundreds of bites.

by Catherine Roberts

SCIENTISTS ARE ALWAYS looking for better ways to foil bugs that leave itchy welts in their wake. Despite the many tools being studied, from tick-killing fungus to genetically modified mosquitoes, bug repellent is still "the first line of defense," says Mustapha Debboun, PhD, a medical and veterinary entomologist. "It's a personal protection measure that any individual can take into their own hands."

It's an important one, too. In the U.S., the mosquito-borne West Nile virus is thought to have infected nearly 7 million people since it first appeared in New York in 1999, and every year close to half a million people get Lyme disease after a tick bite.

But not all repellents provide equal protection, which is why CR tests how well each one blocks real bugs from biting real people. Our brave participants place repellent-covered arms inside cages filled with 200 disease-free mosquitoes. Then we measure how long it takes the bugs to start biting. And it turns out that what matters most is not the brand or type of repellent (spray, lotion, or wipe) but the active ingredient and its concentration.

The list of products we recommend changes slightly from year to year, but insect repellents whose active ingredient is deet, at concentrations of 25 to 30 percent, reliably earn our recommendation, as do many (but not all) 15 percent deet sprays. We've also found that some (but again, not all) repellents with 30 percent oil of lemon eucalyptus (OLE) and 20 percent picaridin provide long-lasting protection.

But what exactly are these ingredients? And why do some products work better than others with the same active ingredients? Here, answers to those questions and more.

Q What's so great about deet?

When it comes to active ingredients that can ward off bugs, it's hard to beat deet. It's "broad spectrum," meaning it works on a wide variety of bugs, including mosquitoes, ticks, and flies. When scientists are testing the effectiveness of new insect repellent ingredients, they compare them to deet to see how they measure up.

Deet was discovered in the 1940s essentially by "brute force," as Matthew DeGennaro, PhD, an associate professor in the department of biological sciences at Florida International University puts it. The U.S. military and the Department of Agriculture jointly screened more than 6,000 different compounds looking for ones that would repel mosquitoes. A chemical closely related to deet was found to be highly effective, then refined slightly to reduce its tendency to irritate skin. Thus N,N-diethyl-meta-toluamide, or deet, was born and eventually registered for use in consumer products in 1957.

Though scientists found out long ago that deet works, they still don't know exactly why. Theories abound. Deet may mask the odor of humans, confuse the odor-sensing abilities of mosquitoes, or simply compel them to move away, perhaps because it resembles a natural substance they've evolved to avoid. But it may be more than just odor at work. Even mosquitoes bred without the ability to sense the smell of deet appear to sense the chemical with their legs when they land on it, and fly away without biting, according to a 2019 study published in the journal Current Biology.

It's also possible that deet is so effective against mosquitoes because it's working on more than one and maybe several levels at the same time, says Chris Potter, PhD, an associate professor of neuroscience at the Johns Hopkins University School of Medicine who specializes in insects' sense of smell.

Why deet also repels ticks is even less understood, though the mechanisms are likely different than with mosquitoes. Ticks don't have the same odor-sensing body parts as mosquitoes. Instead they have a sensory mechanism unique to ticks called the Haller's organ, which we still know very little about, according to Bryan Cassone, PhD, an associate professor of biology at Brandon University in Manitoba, Canada. But scientists think it's the main way ticks sense their surroundings.

One thing we do know: Ticks, which generally hitch a ride as you pass them in brush or tall grasses, are less likely to attach themselves to your skin if they sense deet, and they'll avoid spots on your skin where deet is. That's one reason it's important to apply repellent carefully to all exposed skin when you want to avoid ticks, Cassone says.

Q Okay, deet works. But is it safe?

Deet has been available to consumers for more than 60 years, and it's estimated that people use it millions of times each year. In all that time, scientists have found only a few cases of harm potentially linked to it.

A 1998 Environmental Protection Agency analysis investigating health effects of deet, for example, found that since 1960, the estimated incidence of seizures with a possible connection to deet exposure was 1 per 100 million users. A 2007 EPA chemical summary report on deet reported that many of these instances of adverse neurological effects were linked with ingestion or "repeated dermal exposure or accidental ingestion of DEET that were

ILLUSTRATION, PREVIOUS SPREAD: MACROVECTOR/SCIENCE SOURCE

why natural repellents don't work as well

THE BOTTOM RUNGS of CR's insect repellent ratings are filled mostly with so-called "natural" insect repellents, meaning those whose active ingredients are essential oils. Lemongrass oil, cedarwood oil, citronella oil, and peppermint oil are among the common ingredients.

It's not that these ingredients don't work. After all, they come from plants that have been repelling insects "for millions of years," says Joel Coats, PhD, a distinguished professor emeritus of entomology and toxicology at Iowa State University. But there's a problem: The molecules that make up many of these essential oils, known as terpenes, are small and light. So although "they're very effective repellents," according to Coats, they evaporate quickly from skin, which means they don't last very long, sometimes for only an hour.

Also, the quality or potency of essential oils is highly variable and unpredictable, says Aaron Gross, PhD, an assistant professor of toxicology and physiology in the department of entomology at Virginia Polytechnic Institute and State University. And while essential oils might seem safer, some people can be hypersensitive or even allergic to them.

Research is ongoing to discover or develop plant-based repellents that will evaporate less quickly. And a few more

Ben's Tick & Insect Repellent Wilderness Formula Pump $6

95 OVERALL SCORE

not consistent with label directions." In other words, deet may pose some risk if it's ingested or used improperly. Keep repellents well out of kids' reach.

And high concentrations aren't necessary. CR tests deet repellents in concentrations only up to 30 percent. More than that just isn't needed to get long-lasting protection.

When you use deet-powered repellent as directed, it poses very little risk. The Centers for Disease Control and Prevention recommends it as a safe option for adults, children older than 2 months, and even people who are pregnant.

Still, no chemical is without risks, and deet needs to be used properly

TIPS FOR APPLYING REPELLENT

APPLY BUG SPRAY TO EXPOSED SKIN AND CLOTHES
Never apply it under your clothing because it could cause skin irritation. Before spraying on clothes, test it out on a small piece of fabric to make sure it won't cause damage.

LEAVE NO SPOTS UNSPRAYED
Mosquitoes and ticks are good at finding unprotected skin. To protect your face—and to apply repellents to children—first spray your hands, then rub on your face or on your child. A thin film of repellent is sufficient. Wash your hands after applying to avoid getting any repellent in your mouth or eyes.

REAPPLY AS DIRECTED
Check the product label for a suggested time frame, which may range anywhere from 2 to 8 hours. A good guideline is to reapply it when you notice mosquitoes are biting again, but some repellents may have limits on a maximum number of applications per day. So reading the label for additional guidance is wise.

effective plant-based repellents are already on the market. PMD, which gives oil of lemon eucalyptus (OLE) its potency, is a terpenelike compound. So is a tomato-derived active ingredient, 2-undecanone, which, like OLE, is registered with the EPA as an effective repellent ingredient. (It's hard to find products with this ingredient on the U.S. market, and Consumer Reports doesn't have one in our ratings.)

There's also a new active ingredient called nootkatone, which is derived from grapefruit skin and Alaska yellow cedar trees. It was registered with the EPA in 2020 and is what's called a sesquiterpene, a heavier terpene molecule. It's so new, in fact, that there aren't any commercial insect repellents on the market that contain it yet. But the EPA's data suggests it should have good efficacy against biting bugs.

how the naturals stack up

Babyganics Natural Insect Repellent
$10
12 OVERALL SCORE

Greenerways Organic Bug Repellent
$9
7 OVERALL SCORE

Hello Bello Mosquito Repellent
$8
4 OVERALL SCORE

in order to be safe. According to the National Pesticide Information Center (NPIC), you should avoid applying deet underneath your clothes (use it only on exposed skin and on the outside of clothing), wash it off your skin at the end of the day, and try not to reapply it too frequently. Neglecting those tips could lead to you getting a higher dose of deet than intended. Plus, deet can degrade certain synthetic materials like plastic, so it shouldn't be applied to some types of clothing.

You may also be worried about the long-term risks of exposure to deet. According to a 2008 fact sheet by the NPIC, "researchers have not found any evidence that deet causes cancer in animals or humans," and there's no clear evidence of other long-term risks of topical use despite the availability of deet for decades.

Q What are OLE and picaridin?

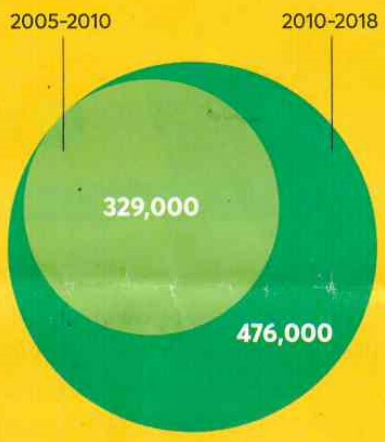
OLE was brought to the attention of U.S. scientists in the 1990s, when they learned that a Chinese product called Quwenling was repelling mosquitoes much better than other plant-based products. One of its major components is the chemical p-Menthane-3,8-diol, or PMD, which gives OLE its repellency.

The name "oil of lemon eucalyptus" is something of a misnomer. The Australian plant it comes from, Corymbia citriodora (or lemon-scented gum), used to be considered part of the Eucalyptus genus but isn't anymore. And unlike lemon eucalyptus oil, OLE isn't a true essential oil because it's refined and concentrated. In short, it's not exactly what it sounds like, though it's indeed a naturally derived ingredient that's often very effective.

Picaridin, also called icaridin, is a chemical that was developed by Bayer AG in the 1980s and 1990s. Its structure is similar to piperidine, a chemical that occurs naturally in certain pepper plants. It has been available to U.S. consumers since 2005 and is especially popular as an insect repellent in Europe and Australia.

the rise of Lyme

IN THE U.S., the range of the black-legged tick (which transmits Lyme disease) has grown over the past two decades, due in part to a changing climate, increased suburbanization, reforestation in the Northeast, and other reasons. Early symptoms of Lyme often include a bull's-eye rash (in 70 to 80 percent of cases) and a fever. Untreated, symptoms can progress to arthritis, nerve pain, and heart palpitations. Today, cases of Lyme—which gets its name from the Connecticut town where it was first identified—are found in nearly every state.



AVERAGE NUMBER OF CASES ANNUALLY*

Q Are OLE and picaridin safe?

Compared with deet, less is known about OLE and picaridin, but evidence suggests that they're safe when used according to the label.

OLE is classified as a biopesticide by the EPA, which means it's a naturally occurring substance considered to be a lower risk than more conventional pest-control chemicals. The main risk appears to be that it can be harmful if it gets in your eyes. It also shouldn't be used on children younger than 3; its safety has not been well studied in young children.

Picaridin carries a small risk of skin irritation, but this appears to be rare. Any possible long-term effects of these two ingredients have largely been unstudied.

Q Why do repellents with the same active ingredients sometimes perform differently?

Our testing can't tell us why some repellents with the same labeled active ingredient last for a long time while others don't. In part, that's because—unlike with cosmetics or other personal care products—manufacturers of EPA-registered repellents aren't required to disclose all of the ingredients. It could be that some of the nonactive ingredients in a given repellent are affecting how well they perform.

Academic researchers are limited in their ability to study commercial insect repellent formulations, says Zain Syed, PhD, an associate professor in the department of entomology at the University of Kentucky. Manufacturers are reluctant to provide their formulas to researchers for testing—they consider them to be trade secrets—so independent scientific studies of insect repellents can't test how a repellent's nonactive ingredients may be contributing to its efficacy.

That's one advantage of CR's insect repellent testing: We perform our tests with the same products that you buy on store shelves. So even though we don't know all of the ingredients in a product, we can see how well it works in comparison with other products on the market.

*Source: CDC

Ratings > **Bug Off** Our recommended repellents, listed below, kept mosquitoes from biting for at least 5 hours—and sometimes up to 8. Testers put their arms into cages containing hundreds of mosquitoes. Itchy yet?

Brand + Product	Overall Score	Cost Per Ounce	Concentration of active ingredient	Claims to protect against ticks	Test Results: Protection against mosquitoes and ticks	Test Results: Resists damage to materials
DEET						
Ben's Tick & Insect Repellent Wipes	96	$4.17	30%	●	⏫	ℹ
Ben's Tick & Insect Repellent Wilderness Formula Pump	95	$1.76	30%	●	⏫	ℹ
3M Ultrathon Insect Repellent8 Aerosol	94	$1.83	25%	●	⏫	⏬
Off Sportsmen Deep Woods Insect Repellent 3 Aerosol	93	$1.67	30%	●	⏫	⏬
Ben's Tick & Insect Repellent Wilderness Formula Aerosol	88	$1.33	30%	●	⏫	ℹ
Cutter Backwoods Insect Repellent Pump	88	$1.33	25%	●	⏫	⏬
Coleman Insect Repellent Ultra Dry Formula Aerosol	86	$2.25	25%	●	⏫	⏬
Off Deep Woods Insect Repellent VIII Dry Aerosol	86	$1.50	25%	●	⏫	ℹ
Sawyer Ultra 30 Insect Repellent Lotion	84	$3.67	30%	●	⏫	ℹ
Repel Insect Repellent Sportsmen Formula Dry Aerosol	76	$1.38	25%	●	⏫	⏬
Cutter Sport Insect Repellent Aerosol	73	$1.33	15%	●	⏶	⏬
Repel Insect Repellent Scented Family Formula Aerosol	70	$0.62	15%	●	⏶	⏬
Cutter Backwoods Dry Insect Repellent Aerosol	69	$1.50	25%	●	⏶	ℹ
Repel Insect Repellent Mosquito Wipes	65	$2.67	30%	●	⏶	⏫
Off Deep Woods Insect Repellent Towelettes	64	$8.11	25%	●	⏶	⏫
PICARIDIN						
Sawyer Premium Insect Repellent Pump	83	$3.00	20%	●	⏫	ℹ
Off Family Care Insect Repellent VIII with Picaridin Aerosol	70	$1.20	10%		⏶	ℹ
Natrapel Tick & Insect Repellent Aerosol	69	$1.67	20%	●	⏶	ℹ
Off Defense Insect Repellent I with Picaridin Aerosol	66	$2.60	20%	●	⏶	ℹ
OIL OF LEMON EUCALYPTUS						
Repel Lemon Eucalyptus Insect Repellent2 Pump	90	$1.25	30%		⏫	⏫
Cutter Lemon Eucalyptus Insect Repellent Aerosol	82	$2.25	30%		⏫	ℹ
Natrapel Lemon Eucalyptus Insect Repellent Pump	72	$2.06	30%		⏶	ℹ
Natrapel Lemon Eucalyptus Insect Repellent Aerosol	69	$2.00	30%		⏶	⏶

> Digital and All Access members can find the latest, complete ratings at CR.org/insectrepellents.

HOW WE TEST: We apply a standard dose of repellent to participants' arms, which they place in a cage of disease-free mosquitoes 30 minutes and 1 hour after application, then hourly until they receive two bites in one 5-minute session or one bite in each of two consecutive sessions. We no longer test against ticks. In the past, we found that repellents that did well against mosquitoes also worked against ticks, but our current tests can't tell us how long a product will keep ticks at bay.

⏬ ⏷ ℹ ⏶ ⏫ POOR — EXCELLENT | ✓ RECOMMENDED $ CR BEST BUY