Designing GMOs for human Mars colonies: Follow the ‘toxic salt’

How do you colonize a planet that’s saturated with toxic salt? The more that we learn about Mars, the more we realize that toxic salt will be an issue and that part of the solution might be to remove it.

Before using the Martian dirt to grow staple grains such as wheat and corn, and especially water-loving vegetables and fruits, we can implement various filtering procedures to remove an ion that’s ubiquitous on Mars and forms salts that we don’t want to ingest. The ion is calledperchlorate (ClO_4^-) and it’s not desirable to have on the menu, because it interferes with thyroid function, so filtering makes sense.

But filtering alone would be a waste, because perchlorate is also potentially useful on Mars for the same reasons that it’s used on Earth: It contains energy and oxygen and lots of it. For that reason, it has been the major component of solid rocket fuel for decades, and today we know that the oxygen and energy in perchlorate also can be utilized by certain microorganisms. Taking those organisms and modifying them genetically for survival on Mars, or doing the reverse—copying genes from perchlorate-loving organisms and giving them to organisms that are suited for the Martian environment for other reasons—humans could create new microbes that could remove the perchlorate and synthesize useful products from it. Some engineered microbes, for instance, could help process the perchlorate into rocket fuel. Others microbes could extract molecular oxygen—O_2 the kind of oxygen that we need to breathe. The current atmosphere on Mars is mostly carbon dioxide (CO_2) with exquisitely low air pressure, but the modified organisms could release perchlorate-derrived O_2 into the atmosphere to help with terraforming—modifying the planet to be more like Earth.

Discovery of perchlorate on Mars: Strange and eventful history

For now, air pressure at the Martian surface is so low that it can barely keep water in a liquid state—unless the water is loaded with salt, which changes water’s properties dramatically. With a salinity of 33.7 percent, the Dead Sea is so salty that you can float. That’s insipid compared with Don Juan Pond in Antarctica where the salinity of 44 percent, but Mars water is even saltier and the reason is perchlorate. Several years ago, images from NASA’s *Mars Reconnaissance Orbiter* (MRO) revealed streak marks suggesting water running recently on the surface, plus data from Mars rovers and from meteorites known to have originated on Mars suggest that regions of the Martian crust have been underwater in the distant past.

Equally as helpful in the search for Martian water, a NASA probe called *Phoenix* landed on Mars in 2008 and soon detected perchlorate in Martian dirt everywhere it looked. Then last September, the MRO, still working diligently from orbit, detected perchlorate in those streaks that seem to have been carved by water, and everything fit together. Water erupts periodically from under the Martian surface and it remains liquid because it’s full of perchlorate salts at concentrations much higher than the salts of Don Juan Pond.

Along with clinching the case for water on Mars, the finding of perchlorate on Mars put a twist on a story that began 40 years ago, when NASA delivered two probes to the Martian surface in the summer of 1976. They were called *Viking* Lander 1 (VL1) and *Viking* Lander 2 (VL2) and each had a chemistry instrument package called a gas chromatograph-mass spectrometer (GCMS) whose measurements seemed to indicate a lack of organic matter samples of the Martian dirt. That was surprising, because, regardless of whether Martian microorganisms were present at the two landing sites, organic matter was expected simply because it was known that Mars was pounded constantly by meteoroids carrying organic matter from space. But the *VL1* and *VL2* probes actually two organic compounds: chloromethane and dichloromethane. The *Viking* chemistry team dismissed these two compounds to be contaminants from Earth, because they were cleaning agents like the ones that had been used to clean the probes before for launching them to Mars. After all, why would it have just those two organic compounds on Mars and no others.

But now we know the answer. You actually *would* have those two compounds on Mars because of the perchlorate. Add perchlorate to a mix of your typical organic compounds like those present in microorganisms or those carried on meteoroids and it produces chloromethane and dichloromethane —exactly what the Viking GCMS devices found.

That solved a 40 year-old mystery, but in an age when we're considering sending astronauts and later colonists to Mars it also gives us a problem, namely that the Martian environment is toxic, at least to us humans.

Health issues of perchlorate on Earth

Perchlorate occurs naturally on Earth and is also produced industrially due to its usefulness in solid rocket fuel. Just as you might be reluctant to purchase model rocket engines that have passed their expiration date, the military and rocket industry avoids using solid fuel in missiles and boosters. Fortunately, most missiles carrying weapons wait around without being used, so after a certain time the solid fuel is replaced. This has led to cases of industry being accused of inappropriate disposal, leading to perchlorate contamination of water supplies. IN 1988, Pacific Engineering and Production Company of Nevada (PEPCON), which produced solid fuel for the solid rocket boosters of NASA space shuttles, had a terrible accident at its Henderson Nevada plant. The Environmental Working Group (EWG) grew increasingly concerned over the years and when EWG heard about a research group in Texas that had developed very sensitive and specific tests for perchlorate, they sent lettuce samples from five states (Arizona, California, Florida, New Jersey, and Texas), some samples from conventional farms, some from organic farms.

The main reason why perchlorate is a health concern is that the ClO_4^- molecule is mistaken for iodide ion by cell transporters that normally deliver iodide into thyroid cells. This can lead to hypothyroidism (under-active thyroid), a problem that's exacerbated by perchlorate because it is favored over iodide in excretion to a mother's breast milk and uptake from the milk to the infant's thyroid, placing infants particularly at risk for hypothyroidism even when perchlorate levels ingested by a mother are fairly low. There is also a possible connection between perchlorate and thyroid cancer, but it was really the hypothyroidism issue that led to EWG investigation.

Lettuce was chosen for analysis because it consumes a lot of water during its growth, so EWG saw it as a possible canary in the coal mine. In 2004, the samples were indeed found to contain perchlorate, and interestingly perchlorate concentration was two orders of magnitude higher in samples from organic farms compared with conventional lettuce samples. The reason has never been resolved, but subsequent studies have suggested that perchlorate levels are not high enough to be a health issue anywhere in the US. Moreover, exposure to nitrite and other agents would overshadow any perchlorate issue in terms of of effects on the thyroid.

Interesting—and providing a connection between perchlorate on Earth and on Mars– is that one source of nitrate fertilizer that was used on both organic and conventional farms in the 20th century was from the Atacama desert in Chile. Naturally occurring perchlorate is particularly abundant in the Atacama. This is one reason why planetary scientists and astrobiologists have been using the Atacama as a Mars analogue environment, a place similar to Mars and thus where equipment destined for the Red Planet can be tested.

Living with the perchlorate on Mars

Unlike the Earth situation, controversy does not surround the question of whether the highly concentrated perchlorate in the Mars dirt would be a health issue for humans. It certain would be, and that's one reason why biotechnology will be key to Martian colonies. When we talk about using genetic modification to survive in the Mars environment with its high concentrations of perchlorate, it doesn't mean editing the genomes of future human Mars colonists so that perchloride will not be toxic. Whatever enhancements might be considered for settlers, whether involving gene therapy or implants, they'll still need thyroids and nothing that we can do will change the chemistry of perchlorate and iodide ions. That means we'll have to remove perchlorate from water, or anything else that humans ingest. But when it comes to microorganisms, we can be a lot more creative, as we've already been in biomedicine and agriculture.

Perchlorate salts are abundant deep in Earth's oceans, where they spew out from hydrothermal vents. Certain species of Archaea and Bacteria flourish around the vents, not only tolerating perchlorate but making good use of it. Molecular oxygen (O_2) from the atmosphere is absent at such depths, but these microorganisms—let's call them perchlorophiles—utilize the four oxygen atoms from each perchlorate just as aerobic organisms use O_2 for drawing energy from food molecules. Though physically closer to us than Mars is, the deep ocean is a very alien environment. It's challenging to reach with instruments the conditions are hostile to humans, so the the perchlorate-thriving Archaea and Bacteria are fairly new to biology. In contrast to well-known microbes like *E. coli*, we're not accustomed to using them in genetic engineering projects. But once the biochemistry and molecular biology of these exotic microbes is understood better, their genes could help open a new biological frontier to go along with the Martian frontier that now beckons to become humanity's second home.

David Warmflash is an astrobiologist, physician and science writer. Follow @CosmicEvolution to read what he is saying on Twitter.