

# NATURAL HISTORY

10/19



HIGH HOPES  
FOR RUBBER  
DANDELION



# Rubber Dandelions

For temperate zone countries, dependent on natural rubber from the tropics, the risk of disruption in supply has led to other sources of natural rubber.

By Katrina Cornish

Loved for the beautiful flower-studded spring meadows they create, or hated as a pernicious plant, nearly impossible to rid from a lawn, dandelions are an incredibly successful genus (*Taraxacum*) found worldwide, diversified into an estimated 3,500 species. They are eaten as salad greens; made into teas, jellies, and wines; and used in folk medicine. The name dandelion derives from the French *dent-de-lion* (“lion’s tooth”), and the vernacular name in French of common dandelion (*Taraxacum officinale*) is *pissenlit* (“wet-the-bed”), because of the well-known diuretic effect of eating dandelion leaves. In folklore, blowing on the seed head, or dandelion clock, until the last seed is released tells you if someone loves you, or loves you not. Many species have similar, familiar yellow flowers, although white-and-pink flowered species are known.

So, what do dandelions have to do with rubber? The

white sap oozing from dandelion roots looks like the latex tapped from rubber trees (*Hevea brasiliensis*, Pará rubber tree, or Brazilian rubber tree), which is the source of all natural rubber used in the world. However, out of an estimated 20,000 latex-producing plant species, only 2,500 species produce rubber, and common dandelion is not one of these. Also, some species make rubber without producing the milky sap made in pipe-like latex vessels called laticifers. The Chihuahuan Desert shrub, guayule (*Parthenium argentatum*), is the best-known example of a non-laticiferous rubber-producing species.

In the 1920s, scientists recognized that a dandelion species native to Kazakhstan and Uzbekistan, *Taraxacum kok-saghyz* (which literally translates to “dandelion root-rubber”), makes high-quality rubber in root laticifers. As part of the Emergency Rubber Project of World War II, the United States obtained seed from Russia, which led to the

*A field of common dandelion in bloom*





plant's earlier common English name, Russian dandelion. The species was tested in field trials in most of the continental U.S. However, "Russian dandelion" is an inaccurate crop name and began to fall into disfavor after the breakup of the Soviet Union, when native regions asserted their claims to their native species.

In the modern era, natural rubber is still a critical component of developed economies. Because it is so ubiquitous in our everyday lives, most people don't realize its importance. In 2018, 13.87 million metric tons were collected by tapping latex by hand from rubber trees, mostly in tropical southeast Asian plantations and small-holdings, even though the species is native to the Amazon rainforest. The latex is approximately one third rubber, which means 42 billion liters of latex—3.7 billion U.S. gallons—were tapped and collected in little cups. About 11 percent of the latex is centrifuged to remove half the water, and the rest is converted to solid rubber. Concentrated latex is shipped to manufacturers of articles such as gloves and condoms, made by dipping formers into latex emulsions; solidified rubber is molded into such articles as tires, bushings, and gaskets.

Rubber trees are restricted to tropical regions and produced as clonal scions grafted onto seedling root stocks. Differences among clones are small, and genetic uniformity makes crop failure a serious potential risk to the global rubber supply. Even if the rubber tree plantations persist, constantly increasing demand for natural rubber and latex (5.2 percent/year), combined with increasing labor costs, restricted expansion of new rubber tree plantings due to deforestation moratoria, and climate change erosion of

suitable growing acreage, mean that rubber trees will not be able to fully address the doubling of natural rubber production expected to occur during the next twenty years. Meeting this demand while minimizing environmental and ecological impacts is going to need biodiversification of the natural rubber supply by farming of other rubber crops in temperate regions.

Biodiversification of global natural rubber is way past due. Very little rubber is now produced in South America because of the endemic fatal rubber tree disease, South American Leaf Blight—a disease caused by the fungus *Microcyclops ulei*. If this disease establishes itself in southeast Asia, the supply of natural rubber will be lost very quickly.

We have domesticated multiple crops to produce starch, oil, and different fruits, nuts, and vegetables. This biodiversification protects essential supplies. If a potato crop fails, wheat or rice may make up the difference in the food supply; soybean oil shortfalls can be supplemented with oil from corn, sunflower, or canola. Even our fuel sources are highly diverse—petroleum, gas, wood, solar, wind, and so forth. Natural rubber is the only critical crop-based product that has no back up. Scientists have not yet developed a marketable synthetic rubber with the unique and essential physical performance properties of natural rubber. However, researchers at the Fraunhofer Institute for Applied Polymer Research IAP feel their biomimetic synthetic rubber, based on the organic components of dandelions, "has superior characteristics to natural rubber," according to Ulrich Wendler, who heads up the project in Schkopau, Germany. Of course, some characteristics of synthetic rub-





ber also are superior to natural rubber (better oil, oxygen, and aging resistance, for example) which is why both types are used today.

Nevertheless, countries in temperate zones must import all natural rubber. The risk of disruption to this supply has led to efforts in northern Europe, the northern United States, Canada, China, Kazakhstan, and Uzbekistan to produce rubber from rubber dandelion and for semi-arid regions, such as the southwestern U.S., Mexico,

Mediterranean countries, South Africa, and

Australia, to produce rubber from guayule.

Over the last fifteen years or so, governments and tire companies have made significant

investments in alternative rubber research and development.

However, rubber dandelion

must be domesticated before it can

be grown as a field crop, because it

is slow to establish and grow

and is easily swamped by

other species.

Historically, humans have

taken thousands of years

to domesticate and improve

crops. Clearly, this is not an

option for alternative rubber crops.

Fortunately, recent progress in

conventional and molecular

breeding and genome-

*Confocal micrograph of a cross section of a rubber dandelion root, with rubber stained blue.*

informed gene editing can enormously accelerate these processes. Such approaches, which select and modify the plant's own genes but don't necessarily introduce foreign genes, can be used to confer domestication traits, such as herbicide tolerance or resistance, or target the flow of carbon from photosynthesis to make larger roots and higher rubber quantities. An in-depth understanding of the genes and enzymes responsible for rubber biosyn-

thesis can inform additional gene-modification approaches to increase rubber yield. Such understanding can also provide selection targets to conventional breeders. However, the potential ecological risk imposed by unintended transfer of a trait to a related species is exactly the same, whatever the origin of that trait (i.e., whether a trait is enhanced through natural selection, deliberate large-scale mutagenesis followed by selection, targeted editing, or foreign gene introduction).

Thus, an obvious concern about new rubber dandelion germplasm grown on farms is the *perceived* risk of contaminating the ubiquitous and very aggressive common dandelion with modified rubber dandelion genes, foreign genes, or with naturally selected traits that potentially could cause ecological harm. Could genes encoding herbicide tolerance or resistance jump from rubber dandelion to common dandelion?

To address this concern, we at The Ohio State University analyzed common dandelions around the world by asking people to send us seed and

GPS coordinates from collection sites. In North America, we found only common dandelion plants that have three sets of chromosomes (triploid) and produce clonal seed with exactly the same chromosomes (and genes) as their mothers. As a result, common dandelions cannot be fertilized by pollen from rubber dandelion, which is a sexual diploid, so genes cannot be transferred through pollination. However, because rubber dandelion is an out-breeding species and produces seed with two sets of chromosomes, one from the mother and the other donated by pollen from a father plant, it may still be possible for common dandelion (a triploid species can produce pollen with one or two chromosome sets) to pollinate rubber dandelion using the pollen type with one set of chromosomes.

Unidirectional reciprocal crosses were conducted, and progeny were evaluated with species-specific molecular markers. In addition, natural hybridization was quantified in plants produced by seeds collected from rubber dandelion plants grown in open-sided greenhouses surrounded by natural common dandelion-infested meadows over three years (approximately 3.35 million plants in all). Hybrids were only detected during one of these years, at a rate of one in 100,000, when pollination was augmented with beehives. Rubber dandelion flowers, fertilized by common



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*Outdoor planting boxes of rubber dandelion adjacent to a meadow of flowering common dandelion*

dandelion pollen from a number of fathers, produced few seeds and these had a low germination rate.

The very rare, true hybrid progeny, confirmed by genetic markers unique to the parents, produced from both natural and deliberate methods, looked more like common dandelion (thin, yellowish green, lacerate leaves), than rubber dandelion (thick, bluish green, only slightly lacerate leaves). Only a few of the hybrids produced viable (clonal) seeds, whereas the rest were sterile. Seeds produced by these apomictic hybrids established and produced identical apomictic progeny. These hybrids, similar to the common dandelion, could grow in competition with perennial ryegrass in planting boxes, which weaker rubber dandelions could not do—all were out-competed and died.

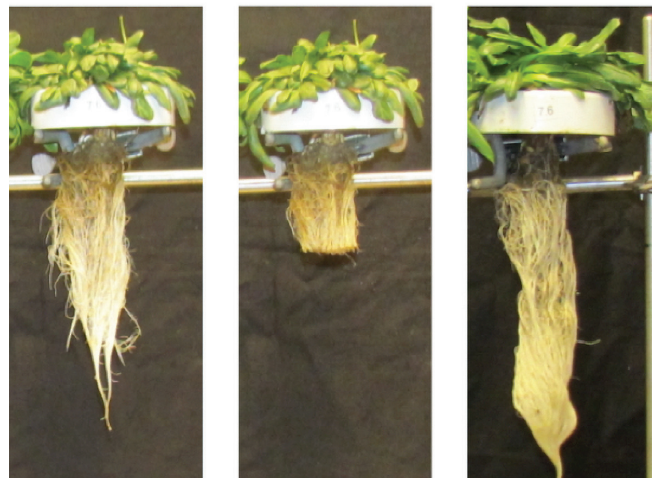
So, gene transfer from rubber dandelion to common dandelion appears not to be possible. In the opposite direction, very rare hybrids produced by diploid rubber dandelion mothers pollinated by triploid common dandelion fathers could not accept pollen from either dandelion species, so they cannot backcross into common dandelion. This means that transfer of risky traits, such as herbicide

tolerance or resistance from rubber dandelion to the common dandelion, is very unlikely, at least in North America. The ability of very rare, potentially herbicide-tolerant, hybrids to persist and become aggressive is not yet known. However, in addition to triploid apomictic types, diploid, sexual, common dandelions do naturally occur in Europe, and rubber dandelions can easily hybridize with these.

Therefore, the principal ecological risk is posed by rubber dandelion seed floating from a rubber field into neighboring fields and becoming aggressive. So far, rubber dandelion is too weak a plant to establish in this way, but it might become a concern if, and when, more vigorous types are created. It seems unlikely that rubber dandelion will ever be as pervasive as the common dandelion.

Until control is fully effective, most research groups working on field rubber dandelion production establish their crops through transplants and control weed growth using a combination of plastic barriers and mechanical and hand culling. These methods are effective but are too expensive and labor-intensive for a commercial rubber crop aimed principally at a commodity market. Direct seeding methods were first successful at The Ohio State University, and other groups are now attempting this. Although planting with seed considerably lowers stand establishment cost, it shortens the growing season (transplants are grown in greenhouses for two months before the fields are warm enough to plant) and leads to smaller plants and lower rubber yields at harvest. Selection of larger, more vigorous plants should overcome this limitation.

Crop density (the number of plants per unit area), rubber concentration, root size, and harvest efficiency are all critical to producing good rubber yield on farms. Our recently published investigation of the effect of plant density and season on rubber yield, performed outdoors in planting boxes, showed that even largely unimproved germplasm, with an average root rubber concentration of around 50 milligram



*Hydroponically-grown roots can be harvested and then regrown on the same plant.*

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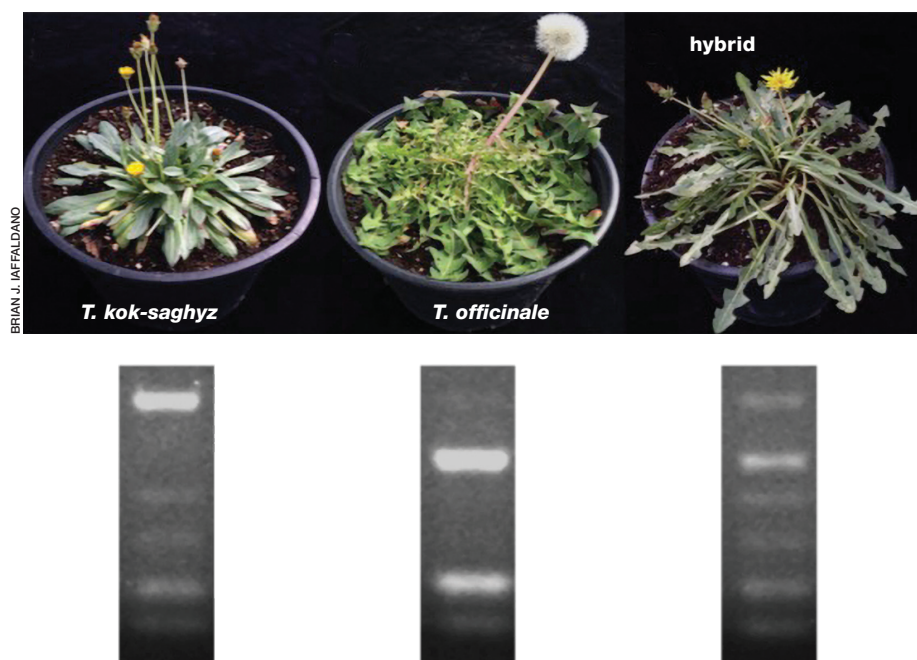
(mg)/gram (g) dry root, could, as a transplanted crop, produce 400 to 900 kilograms (kg) of natural rubber/hectare (ha) in six months, without overwintering. Overwintered plants could yield upwards of 1,000 kg dry rubber/ha. These yields could only be obtained if the planting density is at least 4.94 million plants/ha if grown as an annual crop, and at least 9.88 million plants/ha if overwintered (half the plants died during wintertime, as also happened in a field trial performed at the same time). Now, performance in planting boxes is always going to be better than in fields (even in weed-free fields), so higher rubber concentrations, faster-growing plants, short season-adapted germplasm, and in-field weed control are still required before yields obtained in outdoor planting boxes can be matched or exceeded on farms. Many

times the number of laticifers. Both parameters vary according to the genetics of the particular plant. When we trimmed roots of mature field-grown plants ten centimeters below the crown and then put the plants into hydroponics, adventitious roots rapidly grew from the cut root surface. The rubber concentration and laticifer number per cross-sectional area in both root types were very similar for any individual plant, even though total numbers differed among the different, genetically unique, plants. The living roots from large fall-harvested plants will also make new rubber if stored in dark, chilly barns and root cellars. The plants break down the carbohydrate stores they built up during the growing season, and, because they no longer have leaves to feed, they end up channeling excess sugars to the synthesis of new rubber and rubber particles.

Clearly, we are at least a few years away from widespread rubber dandelion mechanized farming. But this is not our only option, especially if a rubber supply catastrophe occurs and we *must* produce our own rubber in a hurry. Some rubber dandelions grow very well hydroponically, and roots reach a size suitable for rubber extraction in a fraction of the time required in fields. Controlled environment hydroponic production has no weeds or dirt, and plants are not subjected to productivity limitations related to weather, day length, or season. Hydroponics can be extended to vertical farming—a method of growing crops in vertically stacked layers that take up significantly less land than standard farming. This form of 3D controlled-environment agriculture (CEA) is becoming popular for fresh produce. CEA parameters can be controlled to optimize plant growth, including hu-

midity, nutrients, temperature, air composition, and light spectrum and intensity. Some people view year-round vertical farming as the future of farming, due to decreasing available arable land and increasing need for food, especially fresh food, in urban landscapes.

There is another impressive advantage of hydroponic production, which circles back to the *Taraxacum* genus' ability to regenerate after being mowed or damaged. After hydroponic roots are harvested, they grow back—and more quickly than the first batch. The same plants can be harvested multiple times throughout the year, making this 4D system many times more productive than a field crop with one annual root harvest. Although viable yields (of at least 1 ton/ha/year) may be possible in a few years on conventional rubber dandelion farms, using chemical weed



Phenotypes of (left) *Taraxacum kok-saghyz*, (center) *Taraxacum officinale*, and (right) an interspecific hybrid. The DNA gels beneath are species-specific markers confirming true hybridization.

individual plants in our rubber dandelion collection have much higher rubber concentrations than the germplasm used in the planting box study. Germplasm bred for higher rubber concentration and large size would offset the expected lower field performance and may allow even better rubber production levels than those achieved in the planting boxes. The highest rubber concentration seen, so far, was a plant with 218 mg/g dry root weight. Unfortunately, we discovered this *after* killing the plant to quantify its rubber. Nonetheless, this does prove that much higher concentrations than the average are possible within the rubber dandelion species and more examples will be identified using non-lethal selection methods and placing these plants into our breeding program. On an individual plant basis, rubber concentration reflects the number of rubber particles in a root laticifer





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(left) a guayule field and (right) guayule latex

control and optimized fertigation practices, indoor vertical hydroponic systems potentially have at least ten times higher productivity/acre/year and can be built up very quickly.

As domestic rubber crops expand, rubber extraction infrastructure must be expanded in parallel. Latex is harvested from rubber trees by tapping, which obviously does not apply to the rubber dandelion. Here, the roots are harvested, and the rubber is extracted by one of several different methods. Some groups are focused on dissolving the rubber away from the root biomass with powerful organic solvents, but we focus on more sustainable, water-based extraction processes.

Without economies of scale, domestic natural rubber from limited acreages or a few vertical indoor farms cannot be produced at the same cost as the commodity form—not while tropical rubber is harvested from eight million hectares of trees with tappers earning a few dollars a day. Also, even one line of tires would need large acreages and multiple processing plants. So premium markets, with higher margins than commodity products, such as tires, are essential for new rubber crops, such as rubber dandelion, while still small-scale, so that profits can fund expansion. Unlike guayule latex, which has special features that can be monetized (allergy-safe and the best form/ fit/feel/function currently known), rubber dandelion makes rubber, which is almost identical to tropical rubber, including cross-reactions with Type I latex allergy. On the plus side, this similarity makes it an attractive, near “drop-in” material for current manufacturers and high-quality tires have been produced from rubber dandelion (and guayule) rubber. On the minus

side, this means that premium markets are more difficult to identify than for guayule latex. However, hydroponic systems will produce a cleaner, dirt-free rubber, which may have premium, niche applications for which rubber extracted from field-grown roots is unsuitable. The fact that this rubber is produced from dandelions in the United States could create value and support expansion of the crop. Of course, if a significant supply disruption occurs in tropical rubber supplies because of disease or politics, high rubber prices and government subsidies may quickly provide the necessary financial support for large-scale crop production and associated processing plants.

The introduction of dandelion and guayule rubber crops into conventional and/or vertical farms will add a new cash crop option for growers and farmers and reduce dependence on rubber imports. In the long term, production could expand to fully supply domestic requirements and allow the export of excess rubber to other countries.

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