Feature

Flower and maturing seeds of *Cuphea wrightii*.

CUPHEA

Diverse fatty acid composition may yield oleochemical feedstock

Coconut oil and palm kernel oil, feedstock for many oleochemicals, are obtained from trees that grow in tropic climates. Attention on temperate zone crops that might produce lauric and capric fatty acids has focused in recent years on cuphea, a species of plant that can grow in temperate climates. Research now is at a preliminary stage, but European and North American oleochemical producers are watching developments closely to see if some day cuphea might become a domestic source of the short chain fatty acids these companies now import. The following report was prepared by Sara Arndt, assistant news editor for JAOCS.

Last September, Oregon researchers harvested four acres of domestically grown cuphea, a normally wild plant native to Mexico, which synthesizes unusually high amounts of medium chain triglycerides (MCT) in its seeds. A nationwide team of agronomists, geneticists, taxonomists and economists, who presented their views at the first cuphea research and development meeting, is hopeful that 20 years from now the oleochemical industry in America could be using a new source of lauric and capric acids to supplement coconut and palm in the manufacture of surfactants.

Cuphea, pronounced coo′-fee-a, is a species of the Lythraceae family that grows wild in the temperate, subtropical climates of Mexico and Central and South America. The only real constraint on its growth is the availability of water. Otherwise, cuphea can grow in many different soils, including sand and clay, and at a wide range of latitudes.

The promise cuphea holds for industry lies in its unparalleled diversity of fatty acid patterns, which range from C_8 to C_{18}. In this, cuphea is "unique in the plant kingdom," according to one industry researcher, who says that the "wide selection of fatty acid chain lengths" in the oil from cuphea seeds means that researchers can almost "tailor-select" the oil composition they need. The lauric acid content of certain cuphea species makes them a potential substitute for coconut oil, and the capric acid content of others suggests that they could eventually supplement, or replace, petrochemicals in the manufacture of certain synthetic fatty acids.

For some geneticists, the investigation of the cuphea plant is a means to an end. If they can learn the mechanism by which cuphea produces such predominant medium chain fatty acids, they may be able to transfer those genes to another oilseed to create a ready-made domestic producer of MCT oils.

At present, coconut and palm kernel oils are the only commercial sources of medium chain fatty acids, due to their high content of lauric acid. Lauric oils are the least unsaturated of all the commercial fats, containing about 50% lauric acid and smaller amounts of saturated acids with 8, 10, 14 and 19 carbon atoms. Their sodium soaps are hard, stable, soluble and free-lathering, a combination of characteristics which makes them particularly desirable for soap manufacturers.

Lauric acid is the most common and plentiful fatty acid in cuphea seeds. It predominates in 43% of the species studied and comprises 38-83% of the total fatty acid content in many of those species. The average lauric acid percentage in cuphea is 65%, compared to coconut oil which may contain 45-50% lauric acid.

No plant, other than palms, has cuphea's fatty acid composition. However, the volatility of the palm kernel and coconut oil markets concerns industry buyers in America and Europe. The U.S. presently imports a total of approximately 660,000 tons of coconut oil per year, which, according to Joe Smith of Oilseed International, is not a large volume compared to the international trade in soybean oil, but represents a steady and increasing demand.

Smith says that oil mills crushing copra in the United States have "gone by the board" since 1974. Coconut oil production now centers on the Philippines and Indonesia, where droughts and bad harvests occur on an average of once every five years, and where domestic consumption of the oil produced increases every year. American agronomists are not seeing the expected re-investment in new hybrid fast-growing coconut plantations in the Philippines. Many of the existing trees, which were planted after World War II, are already old and getting older. In addition, Smith says, the accelerating political and economic problems in the Philippines–particularly the game-playing within the country as to who will control the price and direction of exports–makes the situation a "purchasing agent's nightmare." Development of cuphea as a domestic source of lauric acid which could substitute for coconut oil could offer stability to the U.S. market and provide a new cash crop for farmers.

Dr. Ronald Sampson, a specialist in the product development of industrial chemicals, gives the figures for lauric oil consumption in the U.S. as about 500 million lbs in 1983-84. The production of soaps and fatty acids claimed about one-third of this total. However, as Sampson points out, the potential chemical markets for cuphea are not limited to the markets for lauric oils. Cuphea promises to expand the market beyond what exists today, with prospects bridging into petrochemicals and fitting neatly into today's continuing concerns for renewable resources.

Sampson sees cuphea's advantages as:

–a unique, highly specific medium chain triglyceride composition;

–wide genetic diversity;

–ability to form stands naturally, which aids agricultural cultivation;

–adaptability to different climates;

–potential for relatively high yields, and

–potential as a new crop for U.S. farmers, non-competitive with existing crops.

The high content of capric acid (C_{10}) in some strains of cuphea has led some industry representatives to speculate that cuphea could encourage market growth in areas of the fatty acid industry which now depend on petrochemical imports. Historically, petrochemicals have provided alternative raw materials from which synthetic medium chain triglycerides can be distilled. With a capric acid content of up to 87% in some strains (in one as high as 92%), cuphea could be used as a renewable resource in the production of plasticizers and lubricants, allowing the U.S. to cut back on petrochemical imports.

In a study, "Agronomic Potential of Cuphea, a New Oil Crop," Frank Hirsinger, leading cuphea researcher at Oregon State University, found five different fatty acid patterns in cuphea. Some species, such as *C. leptopoda*, synthesize very high amounts of capric acid (C_{10}); others produce high amounts of lauric acid (C_{12}), as in *C. aperta*, or caprylic acid (C_8), as in *C. cyanea*, or even myristic acid (C_{14}), e.g. *C. palustris*.

Karl Zilch, technical director at Emery Industries, believes that the demand for cuphea will come from the soap and detergent industry, and that other uses for the oil and meal must be secondary considerations. In order to attain crop uniformity, he would advise researchers to concentrate on the species they want to grow–in this case, those with high lauric acid content–and on the oil composition they need before too much diverse work is done with the crop. Others say it would be a mistake to narrow to one strain too quickly and that it is imperative to keep the genetic base large, since cuphea will be a plant to yield more than one product. The lauric oils will lead the way at first because a market already exists; market development may be slower for the capric oils cuphea produces.

Shirley Graham-Cuphea Specialist

When Shirley Graham picked cuphea as a thesis topic for a doctorate in botany in the early 1960s, she had no thought that the results of her research would have any economic value. Her advisor, a specialist on Mexican wild plant genera, suggested she study the Lythraceae. Of all species in that family, cuphea seemed to Graham to be the most appealing. A genetic group of 260 varieties, it provided a fascinating, varied and accessible topic for taxonomic research.

Graham first became involved with the Henkel company's work, through Frank Hirsinger, ten years ago. Since then, she has made numerous field trips to Mexico and Brazil, frequently with her husband, Alan Graham, a botanist, and recently with her 14-year-old daughter, collecting cuphea germplasm for research projects in Europe and the U.S. Dr. Graham

keeps her own extensive collection of the plants, working at home and at Kent State University, where she is adjunct professor and Laboratory Coordinator of Biological Sciences. Her contribution to the development of cuphea as a domesticated plant has involved collecting and identifying seeds from as many species as possible. However, Graham's interest is in pure science and the focus of her work is the genus itself–its evolutionary history, its systematics and its relationship with other plants. Since 1964, she has published extensively on the Lythraceae family, specifically cuphea, and today is recognized as the world's expert on the cuphea species. Graham's goal is the complete taxonomic classification of cuphea, the only one ever to be published in the English language and the first since Koehne's classification (in German) published in the late 19th century.

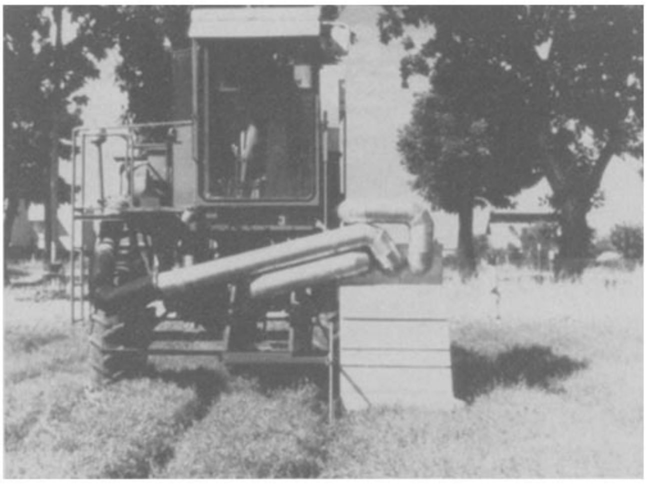
Domesticating Cuphea will be a long process

Unlike other starter crops, cuphea is a wild plant which must be domesticated, not simply adapted to the U.S. In this case, researchers are starting from zero. Some question whether "doing a lot of biochemistry" at this stage is valuable until agronomists know whether cuphea is possible to grow and worth growing. However, Dennis Ray, professor and cuphea researcher at the University of Arizona, comments that plant geneticists cannot breed "in a black box"–a knowledge of the biochemistry must come first. So far, there has been no definitive analysis of the total content of cuphea seeds due to limited supplies of germplasm, which is why breeders are requesting greater effort in the area of germplasm collection.

Agronomic research in Oregon, primarily Frank Hirsinger's, has centered on several small plots, each about one-third of an acre in size. Preliminary findings indicate that cuphea has potential as a domestic crop which palm and coconut could never have in the U.S. Cuphea adapts well to the Oregon Willamette Valley climate, indicating that it probably can grow anywhere with a warm summer and good irrigation. Its natural habitat is the moist, temperate, woody areas of South and Central America, particularly Brazil and the mountains of Western Mexico. Shirley Graham, taxonomist and cuphea specialist, has spent the past 20 years collecting and observing over 260 species of this small wild plant. She explains that cuphea has an enormous diversity in the wild, and often occurs in marshy areas, on river banks, in limestone rocks or even in standing or running water. *Cuphea wrightii* probably has the largest distribution, stretching as far as the southern U.S., but most cuphea species are limited to only one state. Cuphea is one of 25 genera of the Lythraceae family and is, according to Graham, the most advanced of the herbaceous genera in evolutionary terms. The plants and flowers vary widely in morphology, growing from a few inches to several feet tall, with a range of floral colors from light pink to deep purple, and a significant diversity in seed size. Graham says that, in general, the larger flowered species will tend to produce C_8 and C_{10} fatty acids, whereas the smaller ones will contain C_{12}.

A few cuphea species are self-pollinating, although most are cross pollinated by long-tongued bees or hummingbirds which can reach the nectar in a long, tubular flower. Cuphea has a natural uniformity (each plant is a repeat of the parent) and tends to exhibit a high seed set and uniform oil content. According to Graham, there also is some evidence of natural hybridization which would permit crossing species of cuphea in the labs.

Annual, herbaceous species of cuphea will bloom in the first year,



1. A modified cotton picker sucks seeds from cuphea plants through a wide nozzle.

unlike, for instance, jojoba, which takes about five years to reach maturity. The plant tends to grow well in stands (that is, it has the ability to grow densely by continuous formation of side branches) and grows about 2 feet tall, with woody branches about 2-7 mm thick. Cuphea plants flower approximately two months after planting, first on the main stem and later on all branches, and continue to flower and set seed for the next two months. Flowers have six pink petals, the ripened seeds are yellow to dark brown and lens shaped (the size of a flat rapeseed) weighing about 1.6 g to as much as 3-4 g per thousand. Single plant yield projections suggest the potential for 1,000-2,000 kg of seeds per hectare, and even higher. However, current field yields are much lower (200-800 kg per hectare). Oil content can reach 42%, but normally is around 35%. In limited feeding trials with cuphea meal, no acute toxicity has been found, but research will continue for some time.

Agronomists working in Germany and Oregon face the same problem which has confronted jojoba researchers, that of domesticating a wild plant. In spite of its promise, cuphea exhibits some common wild plant characteristics that limit its agronomic potential. Adaptation of the plant for economic production will depend on overcoming problems such as dormancy conditioned by hard seed coat, sticky glandular hairs on stems and flowers, indeterminate flowering and early seed shattering.

Seed shattering is associated with the "zygomorphy" of cuphea flowers or the asymmetry of its petal formation—the flower is irregular like a snapdragon, rather than rotate like a rose. Graham explains that the zygomorphy of the flower is an outstanding taxonomic trait distinguishing the genus cuphea from other genera of the Lythraceae family. It is a universal characteristic of this genus but represents a major problem for cuphea growers. When cuphea seeds are ripe, the floral tube splits along one side and the placenta, carrying the seeds, stands upright in the air. Hirsinger and P.F. Knowles, in a paper, "Morphological and Agronomic Description of Selected Cuphea Germplasm," (published in *Economic Botany* in 1984) explain that all cuphea species have a thin, parchment-like tissue layer, the fruit pericarp, which does not grow and expand while seeds are maturing. During the first stage of seed development the floral tube provides additional shelter for the seeds, but as they continue to grow, the tube bursts and the cone-shaped placenta, with its attached seeds, breaks through (see photo). Eventually, floral tube and placenta will form a "placenta angle" of about 140°. Although seeds are not fully ripened until a week after emergence, they can be harvested at emergence with almost the same oil content and fatty acid composition as if fully ripe. However, the lack of a protective hull means that the seed attachment dries up very quickly and seed can fall off when touched by rain or shaken in strong winds. For a wild plant, this trait is of enormous importance in dispersing the seeds. In farm

2. Harvested cuphea seeds.

cultivation, this causes extensive problems because the seeds will drop off at the slightest touch. Conventional harvesting equipment is unable to catch a great number of the seeds which fall to the ground.

Modification of harvesting equipment and techniques probably is an easier solution to the problem than extensive genetic work on seed shattering. Scientists at the Department of Agricultural Engineering, University of California at Davis, working in conjunction with Hirsinger, have modified a cotton picker to use vacuum-sucking as an alternative to combine-harvesting for cuphea. The machines have indicated that nondestructive multiple harvests are feasible, even under current undeveloped conditions.

Overhead sprinkler irrigation systems also can cause seed shatter, meaning that farmers would need to use alternative irrigation methods, such as furrow irrigation, floor irrigation or drip irrigation.

Further problems with cuphea crops have been associated with indeterminate growth. Continuous flowering and seed production over a period of one to two months may necessitate multiple harvesting as the only way to ensure maximum seed recovery.

Researchers are still unsure exactly what triggers germination in cuphea seeds. Large-scale cultivation of cuphea will require early and uniform seed germination.

Hirsinger's studies have suggested that *Cuphea wrightii* has the highest seed yield potential of all species studied. *C. leptopoda*, he explains, gives a tremendous yield (more than three or four tons per hectare) but has more drawbacks with sticky hairs and difficult seed germination. According to Hirsinger, perennial species of cuphea are not a worthwhile subject for study since yields are so low (although others believe that the use of hybrid perennials may have an advantage in certain environments). The five species Hirsinger sees as having the greatest potential are *C. wrightii*, *C. laminuligera*, *C. leptopoda*, *C. lanceolata* and *C. paucipetala.* Height needs to be improved in *C. wrightii*, and in all species yields and seed size must be increased, because germination is automatically better with larger seeds.

In the cuphea research projects, the development of improved germplasm is crucial. The role of the USDA Agricultural Research Service unit in Phoenix, Arizona, where cuphea investigation is headed by Anson Thompson, is that of defining the genetics of cuphea in order to consolidate and broaden the germplasm base for research. Dennis Ray, Allen Gathman and graduate student Dave Dierig have been working with Thompson to isolate DNA from several species of cuphea to characterize the species by the differences between types. Their studies of about 400 cuphea plants representing 12 species and several hybrids in greenhouses at the University of Arizona have included rooting studies, the vegetative reproduction of hybrids and work on several mutants. Thompson, who also serves as the USDA/ARS coordinator for the cuphea program, says that the main thrust of his research in Arizona is the use of interspecific hybridization to develop new germplasm to overcome genetic constraints such as seed shattering.

Beyond this, industry will still need to know a great deal more about the oil composition of cuphea, in terms of what else is present in the oil besides the triglycerides (such as wax and phospholipids), and the effect of agronomic and environmental variables on oil composition.

In perhaps as little as five or ten years, researchers could bring cuphea to crop status—that is, the stage of being a viable, growable, usable crop. In order to become a commercial crop, cuphea must have a high seed yield and high oil content with the desired chemical composition. Hull content must be low, and seeds should be large and easy to handle and harvest. Above all, oil should be available at an affordable, competitive price. All this could be well over twenty years away.

The Cuphea Program

The stimulus for today's research on cuphea came from the work done by USDA researchers in the late 1950s and early 1960s. The technological value of the fatty acids in cuphea was first realized in these early analyses but was not paralleled by investigations on the agricultural performance of the material.

Agronomic research was initiated in 1975, due to strong interest and support from the Henkel organization in West Germany. Frank Hirsinger, then a plant geneticist at Goettingen, began his work on cuphea as a graduate student and has become a prominent cuphea researcher in breeding and agronomy. In greenhouses at Goettingen, Hirsinger grew plants from seeds collected in Mexico and transplanted as many species as he could in tiny outdoor plots. From his observations of height, seed set and germination, Hirsinger selected species with the most potential for agricultural cultivation and oil production.

In 1982, Hirsinger was invited to continue research on cuphea at the University of California at Davis. The following year, a combined industry, USDA and Oregon State partnership initiated an agronomic research and development project to study cuphea as a new crop for the U.S. The program's main emphasis is directed toward agronomic research, especially plant breeding and genetics, and also toward seed physiology, agricultural engineering and soil science. Dr. Sampson, seen by his colleagues as the catalyst for the domestic cuphea program, is a technical coordinator of the Committee for Cuphea Plant Research, sponsored by the Soap and Detergent Association's Glycerine and Oleochemicals Division. He sees this pilot project as a precedent-setting program, involving close cooperation and coordination among government at both the federal and state levels, academia and industry. If successful, the cuphea program could become a model for other future crop developments. He says the committee hopes to have a good assessment of whether cuphea crops will be feasible within about 5 years, although commercial crops are still 20 years away. For industry, Sampson comments, this is indeed a long-term investment.