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"Toward the Restoration of an American Classic"

THE AMERICAN CHESTNUT FOUNDATION

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Editor's Notes - Journal Winter/Spring 1994

Over the centuries writers have often likened great efforts to races - foot races, the tortoise and the hare, relay races, and biathlons and triathlons.

The work before the members, directors, and scientists of

The American Chestnut Foundation has all the potential, spirit

and confidence of arctic teams mushing in the Iditarod. What a challenge!

To cover 1,500 arctic miles by dog sled on the strength of a vision and a team, that despite the cold and storms, always pulls together.

Restoring the American chestnut tree is the same kind of grand enterprise, requiring considerable imagination and perseverance - but stretched over

decades, not just miles. As we leave behind our 10th year and enter a new phase, ACF's ability to mush on will depend largely on how well we communicate and inspire each other - daily among ourselves, to the general public and to the next generation.

For this reason we plan to infuse The Journal with new life beginning this

summer. The biggest changes will be in format: expect to see more artwork and photographs, new print types and a range of page designs.

The character of the writing will likely change too as we aim to reach the greatest breadth of our membership: readers will find recollections and stories that capture the soul of our work and solid scientific reports of work in progress.

Board members have suggested new ideas for distribution as well, all with an eye to reaching curious ears that have heard

little more about the American chestnut than once upon a time chestnuts were roasted by an open fire....

There will also be opportunities for members to contribute to The Journal, in the form of letters and photographs, plus some new ways as well.

As we make changes, please forgive the errors and omissions that are bound to occur in any transition. Know simply that we have had a strong start and will continue to gain ground for generations to come!



Life cycle of the chestnut: A composite drawing showing the profile of a mature, forest grown tree; sprouts from a possibly blight-killed tree; a sprouting chestnut pushing up through oak leaves (oak is the primary competitor); and a detail of chestnut burs and foliage.

Drawing by Fred Paillet

Meadowview Notes for 1992

F.V. Hebard Wagner Research Farm Superintendent

EDITOR'S NOTE: *For the sake of continuity, the basic results from work conducted in 1992 at Meadowview have been included in this issue of The Journal. The next issue of The Journal will include complete notes of work conducted in 1993 at the ACF Wagner Research Farm in Meadowview, Virginia.*

In 1992, the Meadowview area was again blessed with abundant, well-spaced rains. However, it was a bit cool in late May and early June, and newly emerged seedlings did not grow as tall in 1992 as in 1991. Refer to Table 1 for the type and number of trees growing at the farm as of February 1993.

Trees continue to bear male flowers one to four years after planting. About 40 percent bear two years after planting. I attribute the precocious flowering to abundant sun, water and fertilizer as well as weed-free soil. Our 1992 nut harvest (see Table 2) was very low, primarily due to a two-thirds reduction in nuts set per pollinated flower.

Of the 572 nuts harvested, only 286 were backcross nuts; the rest were crosses made for research

rather than breeding purposes. In previous years, we harvested about 1.5 nuts per bag and 1 nut per bur; in 1992 we got .7 nuts per bag and .4 nuts per bur.

The number of bagged shoots was about the same in 1992 as it was in 1991. An additional disappointment was that the American trees we used as female parents for the production of third backcross nuts (BC3' 15/16" American) succumbed to blight before setting a nut crop. The 1992 nut set may have decreased because all chestnut trees flowered extremely late. In normal years, we finish pollinating around July 4th. In 1992 we finished on July 20th. We usually gauge flower maturity by the condition of male flowers, however, this year, I believe female flowers bloomed earlier than is normal relative to the blooming of the male flowers. Thus, we pollinated trees later than we should have, past the peak of pollen receptivity of the female flowers. We will keep this in mind the next time there is a late flowering year.

NOTES

Table 1
Type and number of chestnut trees at the ACF Wagner Research Farm in 1992, with the number of sources of resistance and the number of American Chestnut lines in the breeding stock.

Type of Tree	Number of	
	Trees	Sources of Resistance
American	532	0
Chinese	377	36
Chinese x American: F ₁	119	7
American x (Chinese x American): B ₁	261	6
American x [American x (Chinese x American)]: B ₂	687	2
(Chinese x American) x (Chinese x American): F ₂	237	
[Amer x (Chin x Amer)] x [Amer x (Chin x Amer)]: B ₁ -F ₂	422	
Chinese x (Chinese x American): Chinese B ₁	181	
<i>Castanea sequinii</i>	52	
Japanese	77	
American x Japanese: F ₁	3	1
<i>Castanea pumila</i>	1	
Chinese x <i>pumila</i> : F ₁	2	
Large, surviving American	91	9
Luther Burbank Cultivars	10	
Other	49	
Total	3101	

Table 2
American Chestnut Foundation 1992 nut harvest from controlled pollinations

Nut Type	Female Parent	Pollen Parent	Pollinated			Unpollinated Checks		
			nuts	bags	burs	nuts	bags	burs
B ₃	American	B ₂ from Graves B ₁	0	78	*	0	7	*
B ₂	American	Clapper B ₁	187	143	375	4	14	35
B ₂	American	Graves B ₁	99	263	408	1	27	42
F ₁	Nanking Chinese	American	31	66	91	3	8	9
F ₁	Meiling Chinese	American	2	11	18	0	1	1
B ₁	Meiling Chinese	American	2	11	18	0	1	1
B ₁	Mahogany Chinese	Mahogany x Amer	30	65	70	0	6	6
CxB ₁	Mahogany Chinese	Graves B ₁	9	12	14	0	1	2
B ₁ xC	Graves B ₁	Mahogany Chinese	144	50	109	7	5	10
B ₁ xF ₁	Graves B ₁	Mahogany x Amer	70	147	435	3	14	38
Totals			572	835	1520	18	83	143

* Mother trees succumbed to blight before setting a nut crop.

Chestnut Dream Recipes

Recipes are reprinted from the San Francisco Chronicle, researched and written by Sibella Kraus, all supplied courtesy of ACF member John Luigi Chiappe.

Necci - Ricotta filled Chestnut Crepes
From *Italy in Small Bites*,
by Carol Field

CREPES INGREDIENTS:

1 cup + 2 tbs. fresh sweet chestnut flour
1 cup minus 1 tbs. unbleached
all-purpose flour
1/8 tea. sea salt
1/4 cu p sugar
1 ½ cups + 1 tbs. cold water
2 tbs. olive oil

FILLING INGREDIENTS:

½ cup + 1 tbs. ricotta cheese
1/3 cup powdered sugar
½ tea. vanilla
Berry preserves (optional)

DIRECTIONS:

Crepes: Sift both flours with salt and sugar into a bowl. Whisk in cold water and 1 tbs. of the olive oil to make a smooth liquid batter.

Warm a non-stick 6-inch skillet, and swirl remaining 1 tbs. of oil in it over the heat. Pour off oil. Film bottom of skillet with enough batter to cover it in a thin layer. Cook until lightly browned; flip and cook briefly. Repeat, cooking 16 crepes and keeping them warm, wrapped in foil, in a low oven.

The filling: Whir ricotta in a food processor, or press through a sieve. Sift in powdered sugar, add vanilla and mix well. Spread a small mound of filling down the center of each crepe, roll up, and serve

with a spoonful of berry preserves on the side.

Serves 8. Per serving: 215 calories, 4 g protein, 35 g carbohydrate, 6 g fat (2 g saturated), 9 mg chloolesterol, 55 mg sodium, 3 g fiber.

Chestnut Stuffing**INGREDIENTS:**

½ lb. pancetta, (Italian ham) cut into small pieces
2 onions, chopped
1 cup finely chopped celery
½ cup butter
2 cups sliced mushrooms
2 tbs. finely chopped fresh sage
2 tbs. finely chopped thyme
4 tbs. minced parsley
1 to 2 tea. salt
4 cups chestnuts, cooked, peeled, and quartered
4 cups small fresh bread crumbs ~ to 1 cup chicken stock

DIRECTIONS:

Cook pancetta in a large skillet, drain and reserve. Using the same pan, gently saute onions and celery in butter until soft. Add mushrooms, herbs and salt; cook until tender. Mix with chestnuts, bread crumbs and pancetta in a large bowl. Moisten with chicken stock.

Yields about 10 cups. Per cup: 285 calories, 6 g protein, 30 g carbohydrate, 16 g fat (8 g saturated), 34 mg cholesterol, 548 mg sodium, 5 g fiber.

**Biscotti Di Castagna-
Chestnut Short Dough Cookies**

From chef Gary Rulli, Pasticceria Rulli

INGREDIENTS:

4 oz. unsalted butter (softened slightly)
2/3 cup sugar
1 tbs. honey
pinch salt
1 tbs. olive oil
1 large egg pinch cinnamon
1 tbs. vanilla
1 tbs. rum
1 ½ cups chestnut flour
1 ½ cups all purpose flour pinch baking powder

DIRECTIONS:

Mix together the butter, sugar, honey and salt until blended. Add olive oil, egg, cinnamon, vanilla and rum.

Sift together the chestnut flour, all-purpose flour and baking powder.

Combine the two mixtures until they are incorporated, being careful not to overmix. Wrap in plastic wrap and refrigerate overnight.

Roll out dough on a floured surface 1/8 inch thick. Cut into rounds with a 1-inch diameter cookie cutter. Place on a parchment-lined baking tray and bake at 350 degrees for 15 to 18 minutes until golden brown. Let cookies cool on the pan.

These cookies may be eaten plain or sandwiched together with Chocolate-Chestnut Cream Filling (see recipe below).

To fill cookies: Place the Chocolate-Chestnut Filling in a pastry bag fitted with a small round tip. Pipe a round of cream about the thickness of one biscotti on the flat side of half of the cookies; sandwich together with the remaining cookies.

*Yields 40 cookies; 20 filled cookies.
Per cookie: 75 calories, 1 g protein, 11 g carbohydrate, 3 g fat (2 g saturated), 12 mg cholesterol, 12 mg sodium, 1 g fiber. Per filled cookie: 200 calories, 2 g protein, 28 g carbohydrate, 9 g fat (5 g saturated), 29 mg cholesterol, 43 mg sodium, 2 g fiber.*

Chocolate-Chestnut Cream Filling

INGREDIENTS:

10 each marron glace, pureed; or use chestnut paste to equal roughly if to ¼ to 1/3 cup.
4 tbs. butter softened
2 oz. dark chocolate, melted
2 tbs. brandy

DIRECTIONS:

Mix together the pureed marron glace, butter and melted chocolate. Stir in the brandy. Use as a filling for Biscotti di Castagna (see preceding recipe).

Portrait of a Pioneer: Angus W. McDonald, Jr.

from interviews conducted in February 1994



Angus W. McDonald, Finance Committee chair, long-time Journal editor and ACF friend, announced he will step down from his posts due to illness. McDonald continues to be a model of courage in difficult times and in large undertakings. Minneapolis Mayor Sharon Belton declared January 28, 1994 "Angus McDonald Day."

Wind-swept plains, foreign tongues and food, new technology and resurrecting a presumed dead tree species are territories that would intimidate a good many people.

Then there are those who find "wide open spaces" intriguing, challenging and revealing.

For Angus McDonald, The American Chestnut Foundation's long-time Journal editor and friend, sinking his teeth into something and making a difference has been a way of life.

"He saw he could do something and he did it," said American Forests President and ACF board member Donald Willeke. "That's the beauty of the likes of Angus McDonald, and it is in the spirit of the entire American Chestnut Foundation. It's better to light a candle, than to curse the darkness. That kind of a person is always going to find something constructive to do. They're like a tall horse that's willing to lean into the harness and not hold back."

However, sometimes the challenge becomes an internal effort. Last year McDonald was diagnosed with Amyotrophic Lateral Sclerosis, also known as Lou Gehrig's disease. ALS, a virus which is as yet uncharacterized, attacks the motor neurons that control one's voluntary muscles.

True to his way, McDonald is meeting this unknown with courage, "a belief in miracles" and the strength of family and friends who have banded together to form Angus' Chestnuts. He said he also takes part in a clinical program that has been established to test a nerve growth factor.

After years of dedicated service to The American Chestnut Foundation McDonald has stepped down from his posts. But through his insights and example he continues to inspire and encourage us all.

Over the years McDonald has become expert in several fields, including modern Chinese and East Asian history, international business and multi-lingual computer software, and has developed interests in comparative religions and cultures.

He is one of the world's experts on China's Hunan Province, which is larger than the whole country of France, and in 1980 he put together a delegation of most of the scholars who had written full-length studies involving Mao Zedong.

He has held numerous teaching posts both in the United States and abroad, including the University of Minnesota, Stanford University and Sophia University in Tokyo, Japan.

Then there is his interest in the American chestnut.

McDonald and Willeke both recall the day they were discussing trees on the grounds of St. Mark's Episcopal Church in Minneapolis where they are both members.

"We began to talk about trees and their importance in God's creation," said Willeke. "We talked about trees as one of, if not the most important aspect of God's creation. Certainly they are the equals of the mere mortals that plant and tend them and sometimes destroy them."

This conversation occurred just a few years after The American Chestnut Foundation had been established, and Willeke waxed enthusiastic about restoring this once great tree.

"Amazingly I felt energized," said McDonald recounting his first impressions of the work The American Chestnut Foundation planned. "It was a cause one could sink one's teeth into and make a difference."

Willeke introduced McDonald to ACF co-founders Philip Rutter and Charles Burnham. "Of course I had always known about the chestnut in theory," said McDonald. "I thought it was gone like the passenger pigeon. These two people convinced me the chestnut was not necessarily lost."

Willeke tells a similar story about early conversations with McDonald. "What seemed to strike home was here was a group that was trying to do something about the problem rather than just lament the loss. He appreciated that we were trying to help God with the process of recreation. Only God can make a tree, but He's probably got a lot of other things on His mind these days."

McDonald joined the board of directors and became editor of *The Journal* upgrading its format and releasing issues brimming with science, news and reflections. He also joined the Finance Committee and worked together with then ACF Finance Committee Chair Mark Michaud and Treasurer William MacDonald.

For McDonald, being active in The American Chestnut Foundation also brought back to the surface personal memories from his childhood.

"At the Bower, my family's home near Harper's Ferry, West Virginia,] helped my grandfather plant many oak trees in the grove," said McDonald. "My grandfather, E.P. Dandridge, was Bishop of Tennessee during the 40s and 50s, and I guess I absorbed trees and theology simultaneously."

Chestnut trees have also surfaced in McDonald's studies of Chinese history, and their story casts insight on our own problems here in the United States. Currently the Chinese chestnut is not an important agricultural crop compared with the mainstays of wheat and rice, or apples, peaches and leeches; it is considered a secondary orchard tree, according to McDonald. However, it may have been a more substantial tree in the past, he said. Most historians understand that China's big trees were gone by the 15th century.

In the North and in the Yangzi River regions all the big trees were cut, he said.

"The deforestation that occurred in China scares me. I don't want to see it happen in America."

McDonald said this mass deforestation coincided with a decline of other aspects of Chinese civilization. Just as the West began to develop new ways of approaching problems, the lack of timber seems to have been one factor that forced China to turn inward: architecture became constrained; navigation was limited; packaging seems to have turned from wood to cloth. The West had big trees; China did not. I suspect that the modern Chinese chestnut was developed during the same period.

Can Americans learn from this experience? McDonald says obviously technology has changed: we no longer need wooden masts and spars.

"I hope that big trees such as the chestnut will continue to live and die in America," said McDonald. "Trees are an important crop, but we need wild trees including wild American chestnuts. We need their nuts to feed the wild birds and animals. We need their height to lift our spirits. Trees are too important to be left to the forest products industry."

And as McDonald mulls over the enormous challenge before The American Chestnut Foundation, he says the greatest effort will be to actually reintroduce this tree to our forests.

He says we need to take advantage of the high quality work that Fred Hebard

and other scientists are doing, particularly in developing ecologically diverse populations of blight-resistant chestnuts. McDonald says some of these trees will be suited for life in the South; some will be suited for dry sites; and some will be suited for wet sites.

"We have to plant enormous numbers of trees and be prepared to suffer the loss of some that may become blighted or that aren't ecologically suited to their sites," said McDonald. "The scientists are developing important plant material. It is up to the rest of us to help nature restore the wild-American chestnut. We need lots and lots of chestnut seedlings. The American Chestnut Foundation, in my opinion, has a vital role in the quest to restore this American classic."

With this kind of tremendous task ahead staying focused on the work and goals will be a challenge. But McDonald said in his voyages into new territory there has been an approach that has worked for him.

"One of the things that I learned from my grandfather and from a career devoted to the study of history is that you have to pay attention to things, both big and small. You cannot ignore important trends and you cannot forget to wash the dishes," he said.

"Everyone has to find a balance between having your feet on the ground and having lofty goals. My own work has had room for the American chestnut because the tree can contribute to the renewal of America."

Chestnut Meeting in Italy

Reprinted from Connecticut Chestnuts, Volume 1, #2, Winter 1994, Page 3.

In mid-October ACF member Dr. Sandra Anagnostakis of the Connecticut Agricultural Experiment Station traveled to Spoleto, Italy to attend an International Chestnut Congress. This is her report all the state of chestnuts in that region.

It rained the whole week, but the intrepid Chestnuts went out for a look at an orchard anyway. Two tour buses took us north into the mountains to the Vallocchia Valley, drove as far as possible on a small dirt road, and let us out to slog through the mud to see the trees. Orchards in this area do not look like orchards in the United States.

Trees randomly spaced in a forest setting are owned by many people. We were told that about 200 people owned the "orchard" we were seeing, and several families might harvest the nuts from a single tree. Harvest was in process (in the pouring rain) and people were gathering nuts from the uneven ground into baskets and buckets. The trees were very old, many five feet in diameter. They had all been grafted at about five feet off the ground with the local 'Marrone' which has very large nuts. The grafts were made this high because cattle were usually pastured around the trees. They eat the sprouts from the base and would eat off the grafts if they could reach them easily.

Genetic data from Europe suggests that the 'Marrone' are very uniform and that chestnut trees in eastern Turkey are much more diverse. The old dogma is that

the Romans found chestnuts growing in the Caucasus mountains between the Black and Caspian seas where they survived the last ice age. Because they were clearly useful, the practical Romans took seed back to plant all through their empire. Chestnut wood makes good vine supports, so where you find an old vineyard in Europe you will probably find an old chestnut grove nearby - both planted by the Romans.

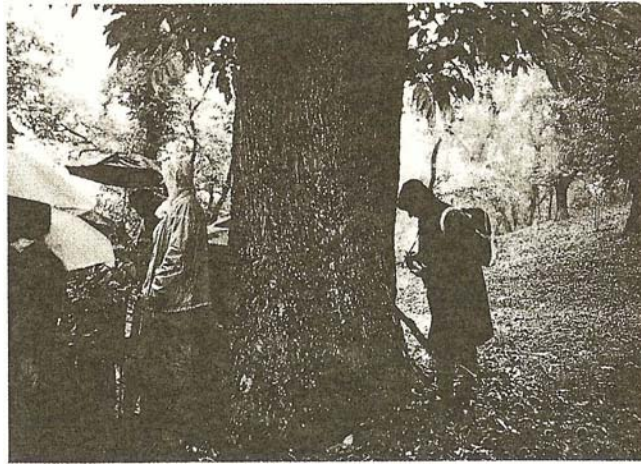
I have been confused recently by leaves from "European" trees in this country with lots of branched leaf hairs. The *Castanea sativa* that I thought typical had only simple hairs on the leaves on the veins, top and bottom. Walking through the old Italian orchard I kept pulling leaves off the trees and checking them with my hand microscope (there were lots of polite Italian men to hold my umbrella). To my surprise, the leaves on the sprouts from old trunks looked European, but leaves from the grafted 'Marrone' had many branched hairs. I would call them a different species, or maybe European x Chinese hybrids. The 'Marrone' are supposed to have been selected by Turkish monks in the 1100s. Did they have Chinese chestnut trees at their disposal?

Marco Polo returned from his famous trip to Asia in 1295, and though he may have brought chestnuts with him, this is probably too late to have influenced 'Marrone' development. The silk trade has recently been studied by economic historians in some detail, and if any of you have

studied this, please call me (203-789-7253)! I am sure that there had been trade of silk with Constantinople by 1100, and chestnuts would have been logical trade items as well.

The resolution of this question is of more than academic interest. Reports of successful biological control of chestnut blight in Italy were considered in the light of our knowledge that *C. sativa* is almost as susceptible to blight as *C. dentata*. If the 'Marrone' have "Asian blood" are they more resistant? Is that why hypovirulence has been so successful in Italy at controlling blight?

I kept asking these questions as we walked through the orchards. The people who really knew about the trees spoke no English. Translation was not easy, even though there were several people there who spoke Italian and knew some English and vice versa. I think that the consensus was that blight showed up first on stump sprouts from the old trees and continues to be most serious on these. The 'Marrone' do get blight, but not as seriously. I probably made enough fuss about this to get some of the Italians thinking about the problem, so perhaps future work will result in some answers.



Last fall, despite the rain, Sandy Anagnostakis and a group of enthusiasts toured chestnut orchards in Italy. A favorite among the Romans, chestnuts were an important orchard tree. Anagnostakis speculates that centuries of trade with the Orient and plantings throughout the Roman Empire may be an important key to understanding current chestnut issues such as hypovirulence.

An American Chestnut Stand in Rockport, Maine

Peter Blanchard

An encounter with a mature, 50-foot - tall American chestnut in the Maine woods is both an unexpected and momentous event. The unmistakable pattern of the furrowed bark, the serrated lanceolate leaves, and in July, the plumes of cream-colored flowers are bound to arrest a progression through a wooded tract of red spruce, white pine, balsam fir, and red maple.

The American chestnut was all but destroyed throughout most of the East, but mysteriously a pocket of 43 American chestnuts continues to persist on an acre tract about mid-way up the coast of Maine.

The spot is The Harkness Preserve, and it is owned by The Nature Conservancy. The conservancy's national mission is to preserve biotic diversity and protect the habitat of rare and endangered plants and animals - the Harkness chestnuts fit well with that goal.

The earliest written record of the chestnuts dates to 1926. Nineteenth century stone walls defining a portion of the preserve boundary offer a possible clue about the stand's origin. While the trees are located at the northern limit of the ancestral range of *Castanea dentata*, which stretches from Georgia to southern Maine, the Harkness trees appear to have been the beneficiaries of a local farmer's efforts and may have been planted in anticipation of nut and timber crops. The oldest and largest of these trees may be 50 years old. Geographic isolation has allowed the trees to escape the ravages of



High up in the canopy, a supporter battles the blight at the Harkness Preserve in Maine. Located on a lone, coastal spot, isolation was the saving grace for this grove of native American chestnuts for many years, but blight has crept in.

the blight until relatively recently. Since the 1980s the chestnut blight (*Chryphonectria parasitica*) has been making inroads into the stand killing several large trees and producing cankers on half of the chestnuts.

The earliest treatments of the blight were carried out by a local forester, Welles Thurber, and utilized hypovirulent strains of the blight fungus donated by Sandra Anagnostakis of the Connecticut

Agricultural Experiment Station. With the best of intentions, Welles found himself in direct confrontation with the preserve's stewardship committee, a group of local residents who volunteer to watch over the preserve, when he cut down two of the largest trees without notifying them. The practice of cutting out and removing dead limbs and whole trees makes very good sense in traditional forestry practice.

A less destructive approach, however, is advocated by Anagnostakis, a mycologist who sees blight spores as being pervasive in a stand. A culling operation which attempts to halt advance of the blight by removing diseased limbs would be similar to an attempt to remove the dust motes riding air currents in a room. Rather, Anagnostakis' emphasis is on large scale conversion of the virulent to the hypovirulent form of the blight.

Since 1989, The Nature Conservancy's stewardship program at Harkness has carried out systematic inoculations of all diseased trees, drawing on the fungal cultures and guidance supplied by Anagnostakis. I continue to culture the French and Italian hypovirulent strains in my farmhouse kitchen in Somerville, Maine, a two-hour drive from the Rockport preserve. To this cultures are added that Anagnostakis has prepared from two Maine hypovirulent strains taken from bark samples of severely diseased Rockport chestnuts thus a truly international fungal mix is introduced into the chestnut trees on our monthly visits during the growing season, from late May to early October. One wonders how, at a microscopic and biochemical level, the various strains fare in each other's company.

The Nature Conservancy's inoculation efforts have faced some technical hurdles. The slurry is injected with an oral syringe

into shallow holes ringing the canker. Battery-powered drills allow for an efficient work pace and coverage of the trees, but carry the danger of drilling too deeply, thus penetrating the xylem and allowing insects and decay fungi to enter.

Anagnostakis has urged the use of cork borers instead which are rotated by hand to produce holes in the bark. However we have found them to be very time consuming and difficult to use in the field given that we may need to treat 25 cankers in a day.

Linda Wirtz, a Nature Conservancy volunteer and her husband Joe, have improvised a cork borer bit for the power drill that is less disruptive to the tree than a standard drill bit. After one or two punches with the borer, though, the tool has to be cleared with a metal rod which slows down the process.

While efforts to curb the blight at levels below 35 feet (the height to which our tallest ladders can reach) appeared effective, we realized that the disease was making its most rapid and devastating progress higher in the trees. In the summer of 1992, we hired licensed arborists, tree climbers who use rope and harness, to scale the heights of the American chestnut.

One of the largest chestnuts of the preserve seemed to be particularly stressed; it was producing a distinctly thinner crown with smaller leaves during the past growing season. When the tree surgeon investigated the area immediately below the canopy, he found an extensive canker which had progressed $\frac{3}{4}$ of the way around the stem. Plastic bags of slurry, a syringe and duct tape to cover inoculation holes were hoisted up to the surgeon at altitude.

The American chestnut trees at the preserve are in a dynamic balance with the blight. Welles Thurber's assessment of the situation was very apt.

"It's as if we've gotten hold of a raging bull by its horns," he said. "We have the hope of controlling it, but it may throw us."

Indicative of this tenuous hold on the blight are the cankers which show a dramatic growth of callus tissue and are healing, and the cankers which once healed that now reveal a re-invasion of the orange pycnidia, those spore-producing bodies of the virulent fungus.

The stand continues to live under assault, and a long-term prognosis for the Harkness chestnuts is difficult to determine at present, thus underscoring the need for a propagation program. Burs have been collected over the years, nuts germinated and seedlings nurtured at Harkness, but large-scale collection and propagation were initiated only recently.

The sweet chestnut, a great temptation, immediately drew competitors to the propagation program, and the services of a cherrypicker were donated to give TNC a head start over the squirrels waiting below. But the machine, donated by Bangor Hydro-Electric Co., arrived after a

windy period and too late in the season; as the volunteers who arrived to help collect nuts put it, the squirrels were lined up to greet the Bangor Hydro-Electric truck. No nuts were to be seen.

Other collection efforts have been more successful and TNC now keeps a galvanized can with a squirrel-proof lid and a sign enlisting the help of passersby in gathering the burs. In the late fall of 1992, chestnuts have been sent to The American Chestnut Foundation, to the Cincinnati Zoo and Botanical Gardens for cryogenic treatment (preservation through deep-freezing), to a landowner in South Carolina who has strong memories of the old giants at the border of his pastures, and to our own restocking efforts in Maine. Some of the nuts may be transported to remote coastal islands in Maine, where hopefully they will gain a foothold.

The cold winds are now whipping down from Canada on this remnant population of a great race of trees. Both the American chestnut and the blight fungus are quiescent as the winter descends.

But with the spring thaw the conflict will resume: a siege between the tree and its blight, between the host and a parasite that behaves more like a predator.

Breeding Blight-Resistant American Chestnut

Albert H. Ellingboe
Professor, Plant Pathology and Genetics
University of Wisconsin at Madison
and
Chair, Science Committee
The American Chestnut Foundation

Introduction

The American Chestnut Foundation was established with the hope of restoring the American chestnut, *Castanea dentata*, to a position of importance as a timber tree and as a source of chestnuts for human and animal consumption. In order to restore this tree, however, we must find a way for the trees to resist the fungal pathogen, *Cryphonectria (Endothia) parasitica*, which causes blight.

The American Chestnut Foundation's breeding program is a test of a hypothesis developed by Dr. Charles Burnham that states resistance to blight is controlled by a relatively small number of genes and that by backcrossing for several generations to American chestnuts it will be possible to develop trees that look like American chestnut.

The concept behind the breeding program is to introduce blight-resistant genetic traits found in the Chinese chestnut to the American chestnut through backcross methods. Some Chinese chestnuts are highly resistant to blight, and they usually cross well with American chestnuts.

Several different sources of disease resistance are used, and several different American chestnut trees are used as recurrent parents. Offspring from such crosses usually survive and develop successfully, and appear to exhibit a reasonably complete range of genetic variability.

The breeding strategy assumes that the genetic inheritance of blight-resistance is less complex than the array of genetic relationships that determine the shape and growth habits of the American chestnut, characteristics we want to preserve; thus, we backcross to the American parent.

The assumption seems reasonable based on experiences in breeding field crops for disease resistance. Commonly, the inheritance of disease resistance looks very complex, particularly if the resistance is obtained from an interspecific cross (a cross between different species), but systematic analysis often shows the inheritance is rather simple.⁵

Clapper^{3,4} has also shown that the segregation for resistance among progeny from a cross of Chinese x American backcrossed to Chinese approximated a 3 to 1 resistance to susceptibility ratio. The ratio suggests that two pairs of genes control resistance to blight. The results also suggested that the resistance to blight was only partially dominant because the presumed homozygotes were more resistant than the heterozygotes.

The backcrossing program was suggested^{1,2,6} because the principal need is to transfer only one trait, that is, blight resistance, into the American chestnut. Theoretically, a Chinese x American hybrid

secondly we would like to select plants in each generation with the greatest similarity to the recurrent parent.

The first point is important because while we are able to cross plants at a very young age, the plants are too young to yield reliable evaluations of blight resistance. To counteract this problem we currently make crosses with a large number of plants in each generation in which the offspring do not appear alike under the assumption that only a few plants will have blight resistant traits. However, using RFLP markers that bracket disease resistance genes, we can focus on parents that are most likely to be resistant to blight.

A second use of the RFLP technology is to select plants in each generation with the greatest similarity to the recurrent parent for each generation of backcrossing. In a typical backcrossing program, the proportion of the genes from the recurrent parent is expected to be $\frac{1}{2}$, $\frac{3}{4}$, $\frac{7}{8}$, $\frac{15}{16}$ etc. for the F_1 , BC_1 , BC_2 , BC_3 , etc., generations respectively. Whether this proportion of genetic material from the recurrent parent is achieved has been difficult to determine. Analyses of segregating generations using RFLPs have shown that the proportion of RFLP markers with the polymorphism of the recurrent parent is often less than predicted in each population. Backcrossing does not apparently move a population toward homozygosity with the recurrent parent as rapidly as predicted from theory.

For example, of four resistant plants one may have the polymorphism of the American parent for only two RFLPs, while another has the polymorphism for seven RFLPs. Obviously, the latter is closer to the American parent than the former.

But by selecting individuals in each generation that have the highest percentage of markers with the polymorphism of the recurrent parent, and using these individuals for the next generation of backcrossing, it is possible to approach the genotype of the recurrent parents in fewer generations than predicted by theory for random selection of individuals for backcrossing in each generation. The potential use of RFLP technology for hastening achievement of goals in breeding of plants with long generation times becomes quite obvious.

Ecological Adaptation

Yet another consideration in breeding the American chestnut for blight resistance is ecological adaptation. The American chestnuts were adapted to a wide geographic range from Maine to Georgia and west to the Mississippi River. It was a dominant species in the Appalachian Mountains. Whether trees adapted to one geographic area will perform well in another area is an interesting question.

Currently much of ACF's backcrossing program involves crossing to American chestnuts within the vicinity of the Wagner Research Farm in Meadowview Virginia. But the Foundation has many members in different regions who wish to be physically involved in the breeding program, and we plan to make pollen available from the backcrossing program for the purpose of crossing onto American chestnuts in different parts of the country. Pollen from resistant plants (of some generation of the backcrossing program) could be used to pollinate surviving American chestnuts in New York, or Georgia, or Kentucky, and other areas. Crosses made with pollen from the breeding program with regionally adapted

American trees should lead to the production of regionally adapted populations of blight-resistant trees.

There is also the possibility that intercrosses among surviving American chestnuts may have low levels of resistance which will yield populations with higher levels of resistance. If some of these trees do, in fact, possess low levels of resistance, they may be useful to incorporate into the backcross breeding program.

Complications

Any program of breeding for disease resistance must take into account that the entity to which resistance is sought is a living entity which can change. Genetically it can mutate, recombine genes, etc., and therefore the breeding program must draw from several sources of resistance.

Each source of resistance must also be backcrossed with American chestnuts to develop blight-resistant chestnuts that are similar in morphology and growth characteristics to American chestnuts. These lines will also have to be tested for their levels of resistance and growth characteristics in several geographic locations.

There must also be a constant search for new sources of resistance. Resistance obtained from different collections of Chinese chestnuts may not have the same genes for resistance to blight. Resistance obtained from Japanese and European chestnuts may be due to different genes that can be used separately or together with resistance obtained from Chinese chestnuts. We know that there is resistance to blight in several species of *Castanea*, but we don't know if the resistance is due to different genes.

The molecular mapping of resistance in interspecific crosses may be very informative in telling us whether resistance in Chinese, Japanese, European, and possibly in American chestnuts is in the same chromosomal locations (which would suggest they contain the same genes) or in different chromosomal locations (which would suggest they have different genes for resistance).

The search for new sources of resistance is also based on the assumption that the introduction of trees from the breeding program will trigger selection within the pathogen population producing new races of the pathogen. Likewise, the breeding may unintentionally develop tree populations more susceptible to pests other than blight that will then become important problems for growing American-type chestnuts. There must be a continuing vigilance for changes in all problems in growing chestnuts.

Testing populations at all stages of the breeding program in various geographic locations should give warning signs of other parasites of chestnuts, and give opportunities to adjust the breeding program accordingly. Production of a blight-resistant plant that is essentially indistinguishable from an American chestnut is only the beginning of a program to restore American chestnuts as a major component of the United States' eastern forests. But to date, thanks to the cooperation of various breeding programs and people with similar goals, the results look very encouraging.

Literature Cited

- ¹ Burnham, C. R. 1981. "Blight resistant American Chestnut: There's hope", *Plant Disease*, 65: 459-460.

SCHOLARSHIP

² Burnham, C. R., Rutter, P. A., and French, D. W., 1986, "Breeding blight-resistant chestnut trees", *Plant Breeding Reviews*, 4: 347-397.

³ Clapper, R. B. 1952, "Relative blight resistance of some chestnut species and hybrids", *J. Forestry*, 50: 453-455.

⁴ Clapper, R. B., 1954, "Chestnut breeding, techniques and results", *J. Heredity*, 45: 106-114, 201-218.

⁵ Ellingboe, A. H., 1981, "Changing concepts in host-pathogen genetics", *American Review Phytopathology*, 19: 125-143.

⁶ Rutter, P. A., and Burnham, C. R., 1982, "The Minnesota Chestnut Program: New promise for breeding a blight-resistant American chestnut", *73rd Annual Report of the Northern Nut Growers Association*.

The American Chestnut Foundation Breeding Plan: Beginning and Intermediate Steps

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Introduction

The American Chestnut Foundation intends to restore the American chestnut, *Castanea dentata* (Marsh.) Borkh., to a position of importance in our eastern hardwood forests. The primary breeding approach we use is to backcross the blight resistance of Chinese chestnut, *Castanea mollissima* Blume, into the American species.³ The basic plan is to hybridize these two species, backcross three times to the American parent, and intercross the BC₃s to recover trees that breed true for blight resistance. We will select seedlings for blight resistance from among the backcross and intercross progeny.

We will not attempt any further improvements to the American chestnut until we are certain the backcross method will succeed, and even then, we would limit improvements to those characteristics which are absolutely necessary to restore the species, in order to retain as much genetic diversity as possible. Improving more conventional aspects of the American chestnut, such as increased that trees with intermediate and low levels growth rate or improved wood characteristics, could be undertaken with trees which we will release to the public. We are using conventional breeding methods and this paper details how we screen progeny for blight resistance, where and how we breed trees, and how many progeny we produce within each

backcross and intercross generation. This paper also explains how many populations, or lines as defined later in this article, of American chestnut we plan to maintain, and the number of sources of Chinese chestnut we will use. The final steps of the program include testing the performance of BC₃-F₂ or BC₃-F₃ generations in forest situations and developing methods for introducing suitable trees back into the forest, but these steps we will discuss in a future article.

Screening Progeny for Blight Resistance

Because current evidence indicates that trees with intermediate and low levels of blight resistance, such as back-cross progeny, cannot be distinguished from each other reliably by direct fungal inoculation until they are 2.5 cm in DBH,⁵ we begin screening for blight resistance when they have achieved this diameter at about 4 to 5 years of age.

In contrast, trees with high to intermediate levels of blight resistance, such as what we expect from intercross progeny, cannot be distinguished from each other by direct fungal inoculation if they exceed 1 cm in DBH (Hebard & Shain, unpublished); thus, intercross progeny are screened when they are 2 years old using the micro-direct inoculation technique

appropriate for smaller trees.

The direct inoculation technique entails removing a plug of bark from a tree and inserting a disk of agar containing mycelia of the chestnut blight fungus into the hole. In the micro-direct method the hole is smaller, about 1 to 2 millimeters in diameter versus 4 - 6 millimeters in diameter for the regular method.

Trees with intermediate levels of blight resistance are being screened for resistance at 4 to 5 years of age; they are planted at 20-foot by 7-foot spacing. Trees with high levels of resistance are screened at 2 years of age, planted at 10-foot by 2-foot spacing. We are using these orchard spacings to eliminate crowding of trees at the time they are screened for blight resistance. These spacings were determined based on experiments done by Uchida⁴ with Japanese chestnut, *Castanea crenata* Sieb. & Zucc. He found that crowded trees were more susceptible to blight than were uncrowded trees; thus, crowding might hamper our ability to distinguish among resistance classes.

Because progenies are not screened for blight resistance until they are several years old, seeds are planted directly into the field.⁷ Compared to transplants from the greenhouse or nursery, direct seeding at orchard spacing results in faster plant growth and requires much less labor.

In the last three years, more than 80 percent of nuts have sprouted and grown. Many seedlings, including pure American chestnut, are bearing male flowers at 1 to 3 years of age, and female flowers at 3 to 4 years.

Trees planted within orchards are arranged in a statistically random fashion. American and Chinese chestnut, their first hybrid and Chinese chestnut cultivars-

'Nanking', 'Meiling', or 'Kuling' - are also planted in the orchards to serve as standards for evaluating blight resistance. Six to ten control plants of each type are planted for every 500 trees.

After trees have been screened for blight resistance, most will be cut down to reduce the amount of blight fungus at the farm. Undesirable trees will be removed as appropriate for space and experimental needs while selected trees will be allowed to resprout. However, those select trees which appear ready to flower will not be pruned, although cankers with blight stromata will be excised.

Pollen is collected from selected trees as soon as they flower. Selected, young trees will be used primarily as pollen parents until the intercross generation to speed up production because numerous female flowers can be pollinated by one catkin. Other factors lead us to use this approach. For example, female flowers yield only one to three nuts and seedling chestnut trees generally bear male flowers prior to female flowers. Likewise, chestnut trees typically bear many more male flowers than female flowers.

How and Where Trees Are Bred?

To maintain adaptations to local conditions and enable us to start breeding trees immediately, as many crosses as possible have been being made on flowering American chestnut sprouts growing at their original locations. Hand pollinations are employed using methods described by Rutter.¹¹ Currently in Pennsylvania, Virginia, North Carolina, South Carolina, Kentucky, Tennessee and Georgia, numerous flowering trees occur in clearcuts, and other disturbed areas, in the national forests. The flowering period

of most chestnut trees occurs between 5 and 10 years after the overstory has been removed.

Flowering is terminated by blight acting together with suppression of new sprouts by competing vegetation. Thus, removing competing vegetation in cutover areas could prolong the flowering period and greatly increase the yield of nuts. In addition to pollinating these trees, we also are planting American chestnut seed, and transplanting naturally occurring seedlings and sprouts to easily accessible locations. Additionally, the ACF distributes American chestnut seed to members so they can raise mother trees for breeding.

Controlled hand-pollination of chestnut is very labor intensive, generally about one nut is produced per pollination bag, and one person does well to place 200 bags in a 12-hour period. There are several alternative methods of producing controlled-pollination progeny which would be much less labor intensive.

First, desirable plants could be grafted onto rootstock in clearcut areas where there is an abundance of American chestnut sprouts (it is necessary to graft at ground level and cover the graft union with soil to exclude blight). Seed from these plants would be pollinated by nearby American chestnut trees.

Second, outside the natural range of chestnut, isolated pairs of trees could be planted with the two trees in the pair making a desirable cross.

Third, in the Midwest there are large, isolated American chestnut trees already growing; scions from other trees could be grafted into the crowns, and ungrafted portions of the crown would supply pollen to the grafts and vice versa.

Fourth, in the East some American chestnut trees survive blight due to

hypovirulence, and many of these flower. If the American chestnut tree is reproductively isolated, nearby Chinese chestnut trees could be grafted with American chestnut above ground level. In the East one can graft above ground level into Chinese chestnut trees, but not into American chestnut trees because blight will rapidly invade the graft union.

One disadvantage of these hands-free methods of pollination is that they take several years to begin producing progeny, but then produce abundantly. Since we do not want a single American chestnut tree to dominate our backcross pedigrees, many of the methods probably would be of limited use in the backcrossing stage of our program, although they could be very useful at the intercrossing stage. Additionally, every year we need F₁ seed to plant as controls, and it can be difficult to avoid pollen contamination with bagged progeny. The hands-free methods could fill this pressing need very well.

How Many Offspring from Each Cross?

The number of offspring needed for each cross can be calculated from the number of genes believed to confer blight resistance. Current evidence indicates that two genes control blight resistance in Chinese chestnut, and several elements point to this conclusion.

Evidence from Clapper's⁴ report shows that about ¼ of the offspring from a backcross of an F₁ Chinese-American hybrid to a Chinese tree had high levels of blight resistance.

Also, the 'Clapper' first backcross⁸ and undescribed 'Graves' first backcross¹ show levels of resistance comparable to F₁ hybrids - these hybrids were selected

from no more than 50 siblings each.

Finally, large F₂ and BC₁-F₂ populations at the ACF's Meadowview farm are being screened for blight resistance (the trees were inoculated in June 1993), and results show that blight resistance is controlled by one to three major genes, probably two. We expect additional evidence will come from the results of screening our backcrosses for blight resistance, and this work is slated to begin this year. Until the number of genes controlling blight resistance is verified, however, our plans assume that resistance is controlled by three genes, an approach that provides a safe margin of error for the program.

In each backcross generation we want to obtain four or five nuts which carry all major genes for blight resistance. From these nuts we should be able to grow two to three trees and select the most American-type trees.

Growing 73 backcross progeny will give us a 99 percent chance of obtaining at least four plants with the three genes, according to the following binomial formula:

$$p = 0.99 = 1 - \sum_{m=0}^3 \binom{74}{m} * 0.125^m * 8.7574^m$$

For intercross (F₂) progeny, the same formula indicates that 604 intercross progeny must be grown to be 99 percent certain of obtaining four plants that will be homozygous for three resistance genes.

However, it would be desirable to produce even more progeny of each cross because then we could select among blight-resistant offspring for American traits, thus bypassing several generations of crosses needed to recover American chestnut traits.² But the space and time requirements of the current method of

screening trees for blight resistance make it impractical to increase the number of progeny we grow.

A genetic, molecular marker approach is attractive in that we might be able to screen offspring for resistance using samples of nut meat or true leaves from freshly germinated nuts. Currently we can generate numerous offspring once trees start flowering, but the rate at which we can advance the breeding program is limited by the time it takes trees to flower.

On the other hand, the molecular marker approach may be too expensive for routine use. Also, molecular markers provide indirect evidence of blight resistance, rather than the direct evidence provided by inoculation. If we use them, we will have to be very careful to ensure that major genes for blight resistance are mapped accurately and that linkages to minor genes are not missed altogether.

However, if there are more than three genes for blight resistance, molecular markers linked to each gene could be used to help backcross them separately into American chestnut, in parallel. Then the genes from the parallel backcrosses would be combined to recover highly blight-resistant trees. It would be preferable if each of these blight resistance genes were detectable by direct-inoculation tests to ensure precision.

Marker-directed selection would also be useful in combining (known as pyramiding) the genes conferring low levels of blight resistance in large, surviving American chestnut trees with the hope of obtaining trees with high levels of blight resistance. Using markers to follow the process, relatively few plants might be needed compared to the number of plants needed under conventional breeding

methods, such as recurrent selection for phenotype. Thor has outlined a conventional breeding program for large, surviving American chestnut trees.¹³

Micropropagation is another tool of biotechnology which could be useful to our program. Micropropagation, cloning chestnuts at the bud stage in tissue culture using plant growth hormones, of highly blight-resistant BC₃-F₂ (or earlier F₂ stages) trees would facilitate evaluating their performance in the field. The technology for micropropagation is immediately available for the small-scale use envisioned here. Micropropagation of selected BC₃-F₂ trees would also increase the production of highly blight-resistant BC₃-F₃ nuts which we intend to use as our primary vehicle for distributing blight-resistant progeny.

How Many Lines of American Chestnut?

The key question is how many lines of trees to advance. Namkoong¹⁰ estimated that "A few thousand samples are needed to save most alleles in most populations ... "In alfalfa, which is a cross-pollinated plant like chestnut, 125 lines were used by Stanford and Houston¹² in backcrossing resistance to bacterial wilt, mildew and leaf spot into 'California Common' to produce the Caliverde variety. We can handle 60 breeding lines at the Meadowview facility. Five additional breeding locales advancing 20 lines each would give us 160 lines.

The contrast between 160 lines and Namkoong's estimate of a few thousand samples makes it clear that the genetic diversity of our products will be less than that which existed prior to blight. It is also clear that we need to breed American



More than a seedling is being planted here. As Fred Hebard guides this Meadowview Elementary School youngster hopefully an appreciation of forest stewardship and scientific study will also take root.

chestnut trees for blight resistance in as many locales as possible!

We define a breeding line of American chestnut as a set of hybrid trees which have the same American chestnut parents. Each American parent of a line is different to avoid inbreeding. In practice, we stretch the meaning of "parent" because we need 73 progeny per line for each backcross step; we cannot generally obtain this many offspring from a single towering American chestnut in the clearcut areas where we do most of our breeding. Thus, we equate each clearcut to a single American parent. We will try to have the clearcuts be no more than 10 km

apart, and at similar elevations. Due to blight, generally it is not possible to use American chestnut trees in a clearcut for more than one backcross generation.

Pollinations in each clearcut may involve multiple Chinese parents, and thus multiple sources of resistance. We are keeping pedigrees and noting when progeny from different Chinese parents have the same American parent tree from a clearcut; use of the same American tree with different Chinese sources occurs infrequently because most American chestnut trees in clearcuts bear only one crop of nuts before succumbing to blight.

Our current breeding program focuses on American trees in the vicinity of Meadowview, Virginia, but our goal is to restore the American chestnut throughout its native range. Thus, to preserve adaptations to local conditions, we hope to replicate at least part of the Meadowview breeding effort every few hundred miles from Maine to Georgia. Alternatively, we could breed trees adapted to local conditions by backcrossing highly blight-resistant BC³-F² trees from Meadowview into local populations followed by a large intercross generation. However, this might require long-term testing to select trees adapted to the local conditions. A few additional backcrosses to locally adapted American chestnut trees prior to intercrossing is a more rapid, but more labor-intensive means of achieving this goal.

How Many Sources of Chinese Chestnut Resistance?

The purpose of backcrossing is to recover all characteristics of the recurrent parent except for the trait being transferred from the donor parent. Thus, a high level of blight resistance is the only characteristic we use in evaluating Chinese, and other chestnut trees, as

sources of blight resistance. For backcrossing, the best sources of resistance are those which confer the most resistance with the fewest genes. Sources are evaluated by the direct inoculation technique to compare their resistance, and that of F¹, F² and backcross progenies. Where possible, F² and backcross progenies from various sources will be interplanted so their performance can be compared.

If two Chinese chestnut cultivars have identical alleles for resistance, creating separate sets of lines for each cultivar would be redundant. We will try to determine whether Chinese chestnut cultivars have identical genes for resistance, hopefully by examining progeny with molecular markers. Molecular markers should at least tell us whether major blight resistance genes are mapped closely together if they cannot tell us whether they are multiple alleles for resistance at the same location.

We have room to carry three sources of resistance in 20 lines each at the Meadowview facility. Twenty lines is the absolute minimum number necessary to preserve genetic diversity on the American side for a single source of resistance.

Three sources of resistance currently have the highest priority at the Meadowview facility. The first source is the triplet of Chinese chestnut cultivars, 'Meiling', 'Nanking' and 'Kuling'. These three cultivars are considered a single source of resistance because they came from the same, or very similar seed lots. They have high priority because in contrast to many Chinese chestnut trees they have demonstrated high levels of blight resistance: there are few, if any, blight cankers on most trees of these cultivars. We have

advanced one line of 'Nanking' to BC₁.

The other two sources of resistance are the 'Graves' and 'Clapper' first backcrosses. The 'Graves' and 'Clapper' sources have high priority because they are our most advanced breeding lines and we wish to test the utility of the backcross method. We are beginning to advance these to BC₃ in blind crosses. Unfortunately, we have only one series of backcrosses to the American chestnut from the 'Graves' and 'Clapper' trees. It will be necessary to develop their genetic bases into 20 American lines. This probably will require one or two additional backcross generations. The Chinese grandparent of the 'Graves' tree is still living, as well as some F₁ hybrids between it and American chestnut. These trees can provide additional lines for the 'Graves' source.

Ideally, we would like to have perhaps 100 individual Chinese chestnut trees comprising our source(s) of blight resistance, in order to maintain genetic diversity at the Chinese genes which remain in our final breeding products. A more realistic figure will probably be ten or twenty because of the pressing need to use numerous American parents.

Conclusion

EDITOR'S NOTE: *This paper explains in detail how we are breeding Chinese and American chestnut trees to produce a blight resistant chestnut that also looks like our American native. As you can see from this article it is a process requiring careful attention to detail from a whole host of perspectives. One way you can get a better sense of the progress we have made at Meadowview is to come and visit! The Wagner Research Farm is open to the public year-round and those who plan longer*

visits can get a hands-on sense of chestnut breeding by helping to pollinate trees in the summer months. For more information on visits and volunteer efforts, please contact Fred Hebard at the farm. He can be reached by calling: 703-944-4631.

References

- ¹ Anagnostakis, S.L., 1992, Measuring resistance of chestnut trees to chestnut blight. *Can. J. For. Res.* 22: 568-571.
- ² Briggs, F. N. and Allard, R.W., 1953. The current status of the backcross method of plant breeding, *Agronomy Journal*, 45: 131-138.
- ³ Burnham, C.R., Rutter, P.A., and French, D.W. 1986. Breeding blight-resistant chestnut trees. *Plant Breeding Reviews* 4: 347-397.
- ⁴ Clapper, R.B. 1952. Relative blight resistance of some chestnut species and hybrids. *J. Forestry* 50: 453-455.
- ⁵ Griffin, G.J, Hebard, F.V., Wendt, R.W., and Elkins, J.R. 1983. Survival of American chestnut trees: Evaluation of blight resistance and virulence in *Endothia parasitica*. *Phytopathology* 73: 1084-1092.
- ⁶ Headling, J.K., Griffin, G.J., Stipes, R.J., and Elkins, J.R. 1976. Severity of natural *Endothia parasitica* infection of Chinese chestnut. *Plant Disease Reporter* 60: 426-429.
- ⁷ Hebard, F.V., and Rutter, P.A. 1991. Growing chestnut trees from seed. *J. American Chestnut Foundation* 5: 110-113.

⁸ Little, E.L., and Diller, J.D. 1964. Clapper chestnut, a hybrid forest tree. *J. Forestry* 62: 109-110.

⁹ McKay, J.W., & Jaynes, R.A. 1969. Chestnuts. Pages 264-286 in: *Handbook of North American Nut Trees*, ed. by R. A. Jaynes. Northern Nut Growers' Association, Knoxville, TN.

¹⁰ Namkoong, G. 1991. Maintaining genetic diversity in breeding for resistance in forest trees. *Annu. Rev. Phytopathol.* 29: 325-42.

¹¹ Rutter, P.A. 1991. Quick guide to making controlled pollinations of chestnut. *J. American Chestnut Foundation* 5: 93-97.

¹² Stanford, E.H. 1952. Transfer of resistance to standard varieties. *Proceedings of the Sixth International Grasslands Congress*, pages 1585-1589.

¹³ Thor, E. 1978. *Breeding of American chestnut*. Pages 7-10 in: W.L. MacDonald, F.C. Cech, J. Luchok & C. Smith, eds., *Proceedings of the American Chestnut Symposium*, West Virginia University Books, Morgantown.

¹⁴ Uchida, K. 1977. Studies on *Endothia* canker of Japanese chestnut trees caused by *Endothia parasitica* (Murrill) P.J. et HW. Anderson. *Bulletin of the Ibara ki-ken Hort. Expt. Stn., Special Issue No. 4*. 65 pp.

Somatic Embryogenesis and Gene Transfer in American Chestnut

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Introduction

American chestnut [*Castanea dentata* (Marshall) Borkhausen] could potentially be restored as a component of eastern hardwood forests if a solution to the chestnut blight fungus [*Cryphonectria parasitica* (Murrill) Barr.] could be found.

Now new tools are available which may have considerable impact on efforts to control chestnut blight. These are the tools of molecular biology. These techniques have already been applied to transform the chestnut blight fungus with a DNA sequence that produces hypovirulence-associated viral dsRNA (Choi and Nuss, 1992).

This transformation permits the transmission of hypovirulence by sexual as well as asexual means, thus reducing the effect of vegetative incompatibility which may have limited the spread of hypovirulence in the United States to date (Anagnostakis, 1977). The release of transformed strains may lead to a greater incidence of hypo virulence in *C. parasitica* populations, however, hypovirulence alone is unlikely to bring about the restoration of the American chestnut as a dominant forest tree species.

Although hypovirulent fungal infections are normally non-lethal, American chestnut stems infected with hypovirulent strains are often badly damaged by multiple infections. Thus, there remains a need to develop American

chestnut trees which are resistant to infection by the chestnut blight fungus. We believe that American chestnut trees which have been genetically engineered to resist chestnut blight would, in combination with hypovirulent fungal strains, provide an integrated system of disease control that would be superior to either one alone.

Similar to the progress noted above with the chestnut blight fungus, recent advances in the fields of plant tissue culture and genetic engineering have provided new techniques that can be applied to develop an effective control for the chestnut blight fungus by modifying the host.

The plant tissue culture regeneration system known as somatic embryogenesis involves de novo production of embryolike structures from somatic cells (Merkle et al., 1990).

In other words, numerous embryo-like structures are engineered in the laboratory through a process that begins with a single, developing embryo and exposes young to plant growth regulators.

Many people believe that in the early stages of embryo development the developmental programming in each cell is still very flexible, and we know that plant growth regulators can control the formation of roots, shoots or other cells.

In this experiment we are encouraging cells to replicate themselves to form clus-

ters of cells. The result is a population of genetically identical chestnut embryos. When the growth regulators are removed, the embryos can often be germinated to produce seedling-like plants. This process is called somatic embryogenesis.

Recently, there has been increasing interest in the potential of somatic embryo genes as a means to improve plants through large-scale clonal propagation of selected individuals with desired genetic traits.

In addition, embryogenic cultures have been shown to be highly amenable to gene transfer; embryogenic cultures have already been used to produce genetically engineered forest trees (McGranahan et al., 1988; Wilde et al., 1992).

We have already reported preliminary results on the initiation of embryogenic American chestnut cultures (Merkle et al., 1991), although optimal culture conditions for embryogenesis were not established and no plantlets were regenerated.

By improving our methods to produce American chestnut embryos and plantlets and combining that with an efficient procedure for transferring genes, we could develop a system for genetically engineering the American chestnut. This gene transfer system may ultimately be used to introduce fungal resistance genes into American chestnut trees. Single gene traits that confer resistance to fungal diseases have gained considerable academic and commercial interest.

Although genes known to inhibit growth of the chestnut blight fungus are not yet available, our overall goal is to develop a reliable system for producing genetically engineered American chestnut trees, so that when such genes are developed, there will be a mechanism readily

available to engineer American chestnut trees with them.

Thus, our approach involves achievement of two objectives: (1) To develop a system for in vitro propagation of American chestnut via somatic embryogenesis, and (2) To define a procedure for incorporation and expression of foreign DNA in embryogenic American chestnut cells. Methods developed to achieve each separate goal will then be combined to produce trees from the transformed cell cultures via somatic embryogenesis.

Methods Used in Somatic Embryogenesis

American chestnut ovules and zygotic embryos from developing burs were used to initiate cultures. Burs were collected from as many locations and from as many individual trees at each location as possible throughout the original American chestnut range. Because fertile American chestnut trees are not common, sources were dictated by the occurrence of fertile trees. During the two years (1991 and 1992) that cultures were initiated, twenty-five trees from locations in New York, Wisconsin, Connecticut, Pennsylvania, North Carolina and Georgia were sampled.

Seed tissues were cultured on two types of basal media: a woody plant medium [WPM] (Lloyd and McCown, 1980) and Driver and Kuniyuki medium [DKM] (Driver and Kuniyuki, 1984), with various combinations and concentrations of plant growth regulators. During the two years that cultures have been initiated, we tested the auxins, 2,4-dichlorophenoxyacetic acid (2,4-D), indole-3-acetic acid (IAA), naphthaleneacetic acid (NAA), and picloram, and the cytokinins, benzyladenine (BA) and thidiazuron.

Treatments of plant growth regulators were applied as follows: (A) no growth regulators; (B) auxin only; (C) cytokinin only; (D) auxin + cytokinin (E) 1, 2, or 3 week pulse on B followed by transfer to A or C; (F) 1, 2, or 3 week pulse on C followed by transfer to A or B; (G) 1, 2, or 3 week pulse on D followed by transfer to A.

Seed tissues from 16 of the 25 trees sampled during 1991 and 1992 produced somatic embryos. Five of these trees produced cell lines that exhibited repetitive somatic embryo production over several months (Figure 1). Those lines that consistently produced somatic embryos had been continuously exposed to a combination of 2,4-D and BA (Treatment D).



Figure 1. American chestnut embryogenic culture showing somatic embryos at various stages of development. (bar = 1 mm) Photo by Daniel T. Carraway

We observed no significant difference between cultures developed on the two different basal media.

And although plantlets have not yet been recovered, somatic embryos produced from our system are now receiving various treatments in order to promote maturation and germination. Treatments include various combinations of cold stratification (some seeds must be exposed to temperatures of about 4° C for

a period of two to three months before they will germinate), drying and exposure to abscisic acid.

We have also started suspension cultures from some of our embryogenic American chestnut cultures by inoculating clusters of developing embryos into a liquid medium. The suspended cultures permit more rapid growth and gene transfer than do the solid cultures.

Gene Transfer

Suspension-cultured American chestnut cells were used for gene transfer experiments in which a Bio-Rad PDS1000/He Biolistics apparatus was used to bombard the cells with microscopic gold particles. These tiny "bullets" were coated with DNA and then accelerated toward the embryogenic cells with a burst of helium gas. Some of the gold particles penetrate the walls of the cultured cells and release DNA into the cytoplasm. Once in the cell, the introduced DNA may enter the nucleus and become part of the plant cell's genetic material.

The DNA used in this project encoded a reporter gene, β -glucuronidase [GUS] (6) and a selectable marker, neomycin phosphotransferase (NPT II), which permits us to identify and separate those cells that have been successfully genetically engineered from those that have not. The process is aided by another condition; when a reporter gene has been inserted into an organism, it produces an easily identifiable trait. Cells that have been genetically engineered with the GUS reporter gene turn blue in the presence of X-glucuronide [Xgluc] (Jefferson et al., 1987).

In plants, selection is usually based on resistance to an antibiotic or herbicide that has been incorporated into the tissue culture medium. American chestnut cells

expressing NPT II are resistant to the drug kanamycin, while non-transformed cells die. Thus colonies of American chestnut cells observed growing after several weeks of exposure to kanamycin are likely to have grown from cells which have integrated the NPT II gene into their chromosomes. Colonies of cells that survive on kanamycin can be checked to confirm that they carry the transferred DNA.

Following bombardment, cells were allowed to stabilize on a medium without antibiotics for 12 days and were then transferred to a selection medium containing kanamycin. After approximately 8 weeks, resistant colonies of cells were visible against a background of dying (nonresistant) cells on some of the plates. Each resistant colony was transferred to its own plate with a fresh selection medium to continue growth. Approximately 10 weeks later, those lines that we believed had been transformed were tested for expression of the GUS reporter gene, using the method described above.

We then extracted DNA from each of the lines and examined it for the presence of the introduced DNA in order to confirm that the foreign DNA had been integrated into the American chestnut cells' own DNA.

Based on the results of assays for GUS expression and the DNA analysis, microprojectile bombardment produced 16 independent lines of transformed cells.

To date, no mature somatic embryos or plantlets have been produced from these transformed cultures. However, all 16 of these transformed lines were derived from a single embryogenic American chestnut suspension, which only infrequently produced well-formed somatic embryos prior to the gene

transfer experiments. Other highly productive lines are available for bombardment, and we intend to apply what we have learned to obtain genetically engineered somatic embryos and plantlets from those lines using microprojectile bombardment.

Conclusion

We have demonstrated that somatic embryos can be induced from immature zygotic embryos of American chestnut, and that micro projectile bombardment is an effective method for genetic engineering of American chestnut cells. We believe that the integration of somatic embryogenesis and microprojectile-mediated gene transfer will allow development of a procedure for introducing blight resistance genes into American chestnut.

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References

- Anagnostakis, S.L. 1977. *Vegetative incompatibility in Endothia parasitica*. *Exp. Mycol.* 1: 306-316.
- Burnham, C.R. 1988. The restoration of the American chestnut. *American Scientist*, 76: 478-487.
- Choi, G.H., and Nuss, D.L. 1992. Hypovirulence of chestnut blight fungus conferred by an infectious viral cDNA. *Science*. 257: 800-803.
- Dennen, H., and Diller, J.D. 1962. Colchipoideity of chestnuts. *For. Sci.* 8: 4350.
- Dietz, A. 1978. The use of ionizing radiation to develop a blight-resistant American chestnut, *Castanea dentata*, through induced mutations. In: *Proceedings of the American Chestnut Symposium* (MacDonald, W.L., Cech, F.e., Luchok, J., and Smith, e., eds.) WV Univ. Press. Morgantown, WV. pp. 17-20.
- Driver, J.A., and Kuniyuki, A.H. 1984. In vitro propagation of paradox walnut rootstock. *HortScience* 19: 507-509.
- Elkins, J.R., Griffin, G.J., and Farias, G.M. Screening American chestnut progeny for blight resistance. In: *Proceedings of the International Chestnut Conference* July 10-14, 1992. Morgantown, WV (in press).
- Jefferson, R.A., Kavanaugh, T.A., and Bevan, M.W. 1987. GUS fusions: B-glucuronidase as a versatile gene fusion marker in higher plants. *EMBO J.* 6: 3901-3907.
- Lloyd, G., and McCown, B. 1980. Commercially feasible micro propagation of mountain laurel, *Kalmia latifolia*, by use of shoot-tip culture. *Proc. Int. Plant Propag. Soc* 30: 421-427.
- McGranahan, G.H., Leslie, C.A., Uratsu, S.L., Martin, L.A., and Dandekar, A.M. 1988. Agrobacterium-mediated transformation of walnut somatic embryos and regeneration of transgenic plants. *Biotechnology* 6:800-804.
- Merkle, S.A., Wiecko, A.T., and Watson-Pauley, B.A. 1991. Somatic embryogenesis in American chestnut. *Can. J. For. Res.* 21: 1698-1701.
- Merkle, S.A., Parron, W.A., and Williams, E.G. 1990. Applications of somatic embryogenesis and embryo cloning. In: *Developments in Crop Science: Plant Tissue Culture Application and Limitations* (Bhojwani, S.S., ed.). Elsevier Science Publishing Company, Inc. New York. pp. 67-101.
- Van Alfen, N.K., Jaynes, R.A., Anagnostakis, S.L., and Day, P.R. 1975. Chestnut blight: biological control by transmissible hypovirulence in *Endothia parasitica*, *Science*. 189: 890-891.
- Wilde, H.D., Meagher, R.B., and Merkle, S.A. 1992. Expression of foreign genes in transgenic yellow poplar plants. *Plant Physiol.* 98: 114-120.

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