WHY WOULD WE BREED CACAO IN FLORIDA?

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Abstract. The U.S. chocolate and confectionery industry is a major consumer of U.S. agricultural commodities. The industry uses over 3 billion pounds of sugar annually, much of it produced in Florida. Over 650 million pounds of milk and milk products, 322 million pounds of peanuts, 43 million pounds of California almonds and 1.7 billion pounds of corn syrup sweeteners are also used. The total value of these U.S. produced commodities is estimated to be over 1.5 billion USD and over 70,000 people are employed in this industry. The seed of Theobroma cacao L. is the only source of chocolate and the plant is not grown commercially in the U.S. Production of cacao in tropical America has been severely affected by two fungal pathogens causing diseases known as witches’ broom (WB) and frosty pod (FP). These, along with another pan-tropical fungal disease, black pod (BP), were responsible for over 700 million USD in losses in 2001. Currently, WB and FP are confined to Central and South America; however, commercial populations in West Africa and South Asia are highly susceptible to both diseases. Traditional cacao breeding programs have only been marginally successful in producing resistant material with suitable commercial characteristics. In 1999, the USDA-ARS, in collaboration with MARS, Inc., initiated a project to apply modern molecular genetic techniques to cacao breeding. The objectives were to develop an international Marker-Assisted-Selection (MAS) breeding program focusing on disease resistance. International collaboration and the development of new disease resistant cultivars are ensuring that crop losses are manageable and contributing to a stable supply of cocoa beans for U.S. companies.

Cacao was cultivated by the Mayan and Aztecs of central and southern Mexico over two centuries ago. They used cacao beans, the seeds of Theobroma cacao, in various rituals, to make a drink, as currency, and for medicinal purposes (Wood, 1975). The Aztecs believed that the god Tula Quetzalcoatl brought seeds with him to cultivate in his garden on earth. This mythological gift is now an important cash crop in the tropics of Central and South America, Asia, and Africa that is critical to the profitability of the multibillion-dollar U.S. chocolate industry.

The U.S. chocolate industry is a primary consumer of a number of U.S. agricultural commodities. Approximately 3 billion pounds of sugar, 653 million pounds of milk and milk products, 322 million pounds of peanuts, 43 million pounds of California almonds and 1.7 billion pounds of corn syrup sweeteners are used annually by the industry. The total value of these U.S. produced commodities is estimated to be over 1.5 billion USD and over 70,000 people are employed in this industry. For every dollar of cocoa imported, the World Cocoa Foundation estimates that between one and two dollars of domestic agricultural products are used in the making of chocolate. The seed of Theobroma cacao L. is the only source of chocolate and, with the exception of a small planting in Hawaii, the crop is not grown commercially in the U.S.

Serious disease and pest problems are a concern for all major cacao producing regions. Cacao cultivation in Central and South America is threatened by two major diseases. Brazil’s main production area in the state of Bahia was devastated by a fungal disease called Crinipellis perniciosa, or witches’ broom after the introduction of the disease in 1986. The fungus penetrates stem and fruit tissue, inhibits pod formation, and destroys the mature pods. Brazil went from being the world’s third-largest exporter of cocoa beans to a net importer of beans in only 12 years. Another fungal disease, monilia pod rot, has forced the abandonment of many cacao farms in Ecuador, Colombia, and Costa Rica. A new species of black pod caused by Phytophthora megakarya has the potential to cause severe losses in West Africa’s cacao production areas. Total losses to the major diseases are estimated at 810,000 metric tons of beans with a value of 761 million USD (Table 1).

Cacao is an out-crossing diploid (n = x = 10) with a genome size approximately 2.8 times larger than Arabidopsis thaliana (L.) Heynh. (Lanaud et al., 1992). Much genetic diversity exists within T. cacao; however, current commercial

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Table 1. Cacao losses due to pathogens in different production regions.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Pathogen</th>
<th>Region</th>
<th>Reduced (tons x1000)</th>
<th>Production ($ million)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Pod</td>
<td>Phytophthora spp.</td>
<td>Africa/america/Asia</td>
<td>450</td>
<td>423</td>
</tr>
<tr>
<td>Witches’ Broom</td>
<td>Crinipellis perniciosa</td>
<td>Latin America</td>
<td>250</td>
<td>235</td>
</tr>
<tr>
<td>Frosty Pod</td>
<td>Moniliophthora voroii</td>
<td>Latin America</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Swollen Shoot</td>
<td>CSSV</td>
<td>Africa</td>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td>Vascular-streak dieback</td>
<td>Onobasidium theobromae</td>
<td>Asia</td>
<td>30</td>
<td>28</td>
</tr>
</tbody>
</table>

*January, 2001; value $940.00/metric ton.

cultivars have a very narrow genetic base (Warren and Kennedy, 1991). The primary types of cacao grown have traditionally been referred to as Forastero, Trinitario, and Criollo, with most of the world’s production based on Forastero-derived types. The Forastero material is usually further divided into upper Amazon and lower Amazon types. The Trinitario are hybrids between Forastero and Criollo types.

In 1955 the U.S. Department of Agriculture initiated a program for the quarantine and distribution of cacao cultivars as a service to the cacao research centers located in the tropics. This activity was divided between two locations with the Miami Station serving as the quarantine facility and the Mayaguez Station maintaining the germplasm. This activity was partially supported by the American Cocoa Research Institute and continued until 1992 when the quarantine facilities and cacao collections at Miami were destroyed by Hurricane Andrew. In 1998 the cacao initiative was revived at both Miami and Mayaguez to provide the quarantine service and germplasm maintenance. In addition to these services, a new research project was funded with the goal of developing a Marker-Assisted-Selection (MAS) program to identify new disease-resistant cultivars.

The primary goal of this project is to select and disseminate new, productive, disease-resistant cultivars of cacao. To attain that goal we are developing tools and breeding enhancement techniques that will efficiently facilitate recurrent

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**Figure 1. Cacao variety development time line.**

- **Variety Development Time Line**
  - Moving resistant material into Africa
  - Selected material identified (parents)
  - Research network forms
  - 1st crosses
  - Field Trials
  - Early screening methods
  - Finding special material (germplasm evaluations)
  - Diversity and pathogenicity analysis of WB and Mo.
  - Developing African and Southeast Asia networks
  - Promising clones and hybrids
  - 1st generation

- **Genomics Time Line**
  - Evaluating disease threat in Africa (Molecular markers)
  - Development of new molecular markers (Microsatellites, RGH, ESTs, and other candidate gene markers)
  - WB resistance markers
  - Ceratocystis resistance markers
  - Moniliosis resistance markers
  - Fat
  - Flavor
  - Yield
genetic improvement. These tools and techniques are being implemented in the project and have been made available to national breeding programs. Research performed in genetic resource evaluation, molecular genetics, statistics, bioinformatics, plant pathology, and practical field selection are all part of a global strategy to develop superior planting material for farmers. New cultivars developed using these techniques will provide the quality and production stability for sustained growth of the confectionery industry.

Specific Cooperative Agreements (SCA) with foreign research institutes including CATIE in Costa Rica, INIAP-Pichilingue in Ecuador, CEPLAC in Brazil, IITA in Nigeria, CCRI in Papua New Guinea, and with the University of Florida, and Florida International University are in place. Each of these SCA supports the international cacao breeding effort providing scientific expertise and field-testing sites for the development of new productive disease resistant cultivars.

The research projects at the Miami lab have focused on developing additional linkage maps and identifying new Quantitative Trait Loci (QTL) for witches’ broom and frosty pod diseases. Most recently a major and minor QTL were located in an F2 mapping population derived from TSH 516 which is a cross of the ICS1 and SCA6 clones. The major QTL explains as much as 40% of the variation for this trait and is being used in the MAS program (Brown et al., 2005). The use of Association Mapping has also been demonstrated using productive and unproductive seedling populations and microsatellite markers. Seventeen of the 65 microsatellite loci used contained alleles that were significantly associated with productive seedlings as determined by Armitage’s trend test. Of these, 13 loci (76.4%) co-located with previously reported QTLs for productivity traits. These markers may prove useful for MAS and demonstrate the potential of association genetic studies in perennial tree crops such as cacao (Schnell et al., 2005).

The use of molecular markers to correctly identify parents in crossing schemes and in past crosses has proven to be important as 20-40% of the accessions in the germplasm collections have been shown to be mislabeled. We have also developed new mapping techniques based on the utilization of half-sib families and this method is being tested on a set of families in the field in Costa Rica (Cervantes-Martinez and Brown, 2004). New methods of identifying candidate genes and turning them into molecular markers have also been developed allowing significant increases in the number of markers for linkage mapping (Kuhn et al., 2005).

MAS is currently underway at CATIE in Costa Rica, INIAP in Ecuador, and CCRI in Papua New Guinea. In each of these locations extensive field tests are identifying high yielding, disease resistant cacao seedlings. The overall goal for the breeding program is to have new cultivars ready for demonstration plantings by 2009 (Fig. 1). The utilization of the new biotechnologies in the application of MAS has greatly improved the efficiency of cultivar selection in cacao. In addition, these techniques are now being applied to other tropical fruit crops such as mango and avocado.

**Literature Cited**


