

# The Future of Cocoa Research: Systems Science in Support of Cacao Farmers



Mark J. Gultinan  
Penn State University  
ISCR – November 13-17, 2017 – Lima, Peru

# What is a Sustainable Cocoa Value Chain?

- ***Economic sustainability:*** All participants earn a reasonable standard of living, retail chocolate prices remain affordable and quality is sustained and improved over time.
- ***Social sustainability:*** Basic human rights of all individuals involved in the production of cacao are respected.
- ***Environmental sustainability:*** No degradation of natural resources necessary for production and no significant negative impacts on the environment or biodiversity.



# Have We Reached Our Goal of a Sustainable Cocoa Supply?



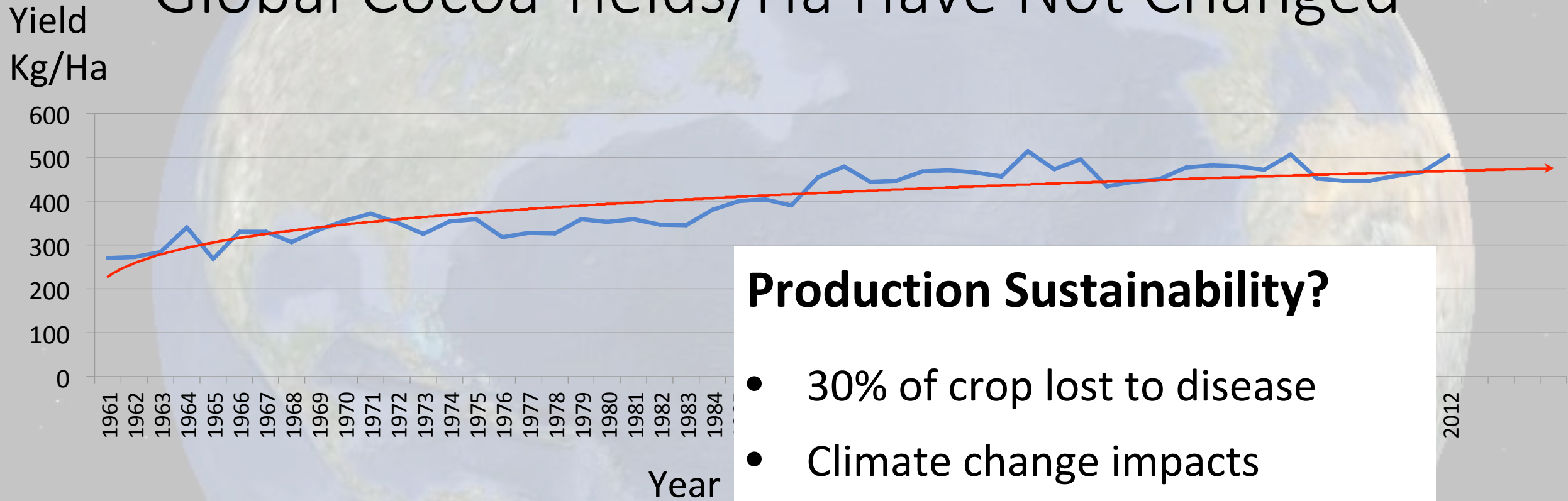
## Economic Sustainability?

- Cocoa price volatility: today price is 33% lower than recent high
- Average Farmer income \$1- \$2/day
- Farm gate price in specific countries only 1/4 of a year ago

Source: International Labor Rights Forum, 2014

## Have We Reached Our Goal of a Sustainable Cocoa Supply?

# Global Cocoa Yields/Ha Have Not Changed



## Production Sustainability?

- 30% of crop lost to disease
- Climate change impacts
- Aging Trees
- Estimated deficits in the future?



# Have We Reached Our Goal of a Sustainable Cocoa Supply?

Tulane University | School of Public Health and Tropical Medicine | Payson Program

Home | Press Releases | Background Materials | Staff | Contact Us

2012-2016 Activities

- About the Project
- Surveys
- Capacity Building
  - Training Materials
  - Child Labor Survey Research Online Short Course
- Findings from 2013/14 Survey of Child Labor in the Cocoa Growing Areas**
- Survey Data Release Policy
- Other Materials and Documents

Home > Findings from 2013/14 Survey of Child Labor in the Cocoa Growing Areas

## 2013/14 Survey Research on Child Labor in the West African Cocoa Sector



2013/14 Survey Research on Child Labor in the West African Cocoa Growing Areas  
[Final Report](#) (English)

## Social Sustainability?

- Overall the number of children working on cocoa farms increased approx. significantly between 2008-2014
- In West Africa alone, an estimated 11 million children participating in hazardous work

Source: <http://www.childlaborcocoa.org/index.php/2013-14-final-report>

# Have We Reached Our Goal of a Sustainable Cocoa Supply?



The screenshot shows a webpage from DAME (Dairy and Animal Magazine). At the top left is a hamburger menu icon. The word "DAME" is displayed in red. Below the header is a photograph of a deforested landscape with a person in a red shirt and yellow hat working in the foreground. The article title is "How Is Our Chocolate Addiction Killing the Environment?" and the sub-header is "Q&A". The text below the title reads: "DAME spoke with environmental crusader Etelle Higonnet, who discovered our love of cocoa is destroying our forests. Is there any way to reconcile our cravings with saving the planet?"

## Environmental Sustainability?

- Cacao growing regions hold some of the world's highest biodiversity
- Overall since 1990 there has been an increase in rate of forest and biodiversity loss
- A part of this is driven by cacao cultivation

Source: <https://www.damemagazine.com/2017/10/27/how-our-chocolate-addiction-killing-environment>



# Have We Reached Our Goal of a Sustainable Cocoa Supply?

**We have made some great progress on all fronts but....  
..... We must do better.....**

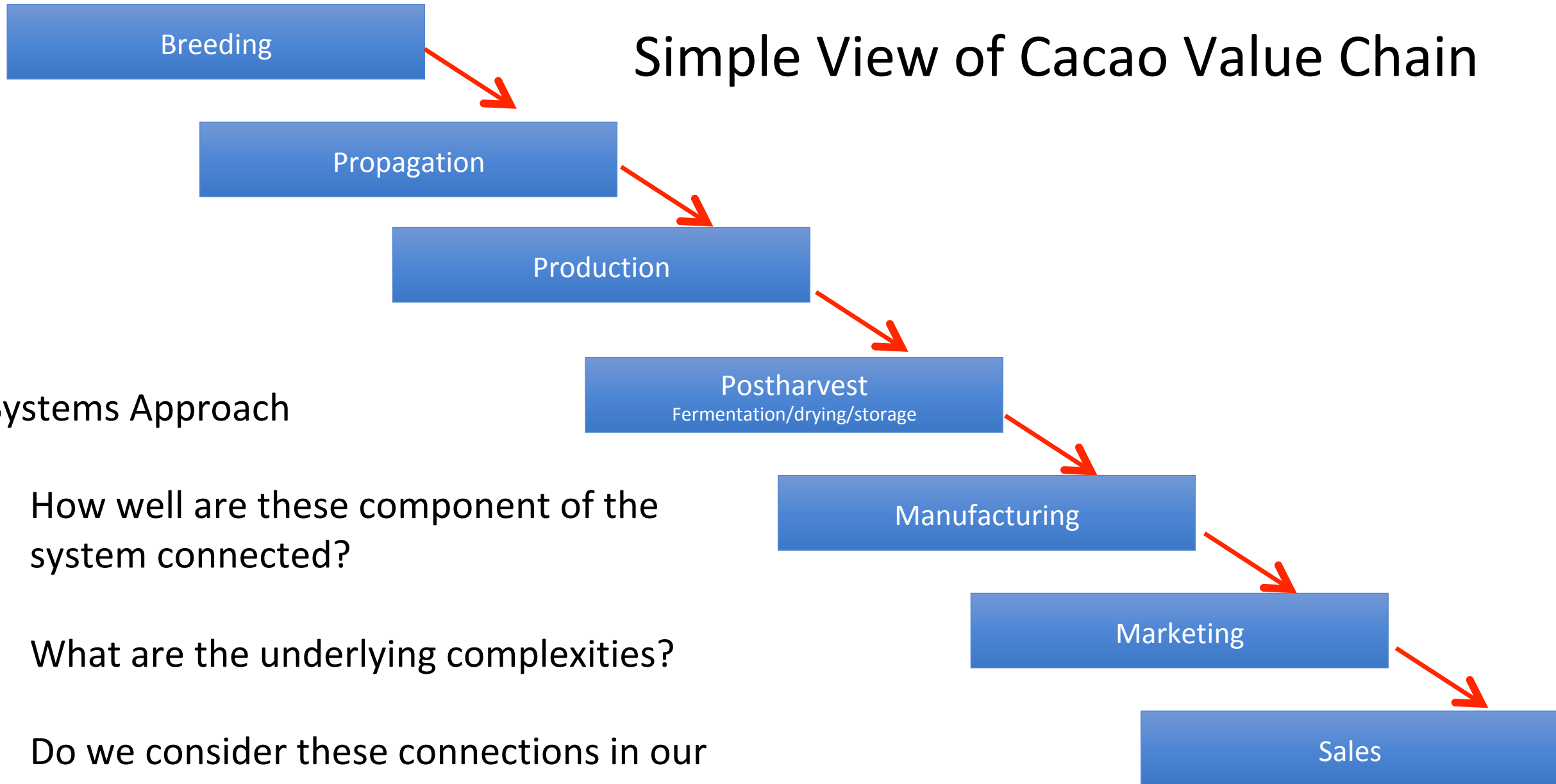
**Why is it so difficult?...**

- A highly complex system spanning many disciplines, countries, work sectors, geopolitical and economic boundaries.
- Will become more complex in future as globalization and interconnectedness continues to increase at rapid pace. Increased communication: accelerated and amplified economic feedback loops.

How to improve such a complex system?

**Systems based research and development approaches.**

# Simple View of Cacao Value Chain



## Systems Approach

- How well are these component of the system connected?
- What are the underlying complexities?
- Do we consider these connections in our research? (enough)



# What is a System?

Merriam-Webster Dictionary: A system is defined as a regularly interacting or interdependent group of items forming a unified whole.

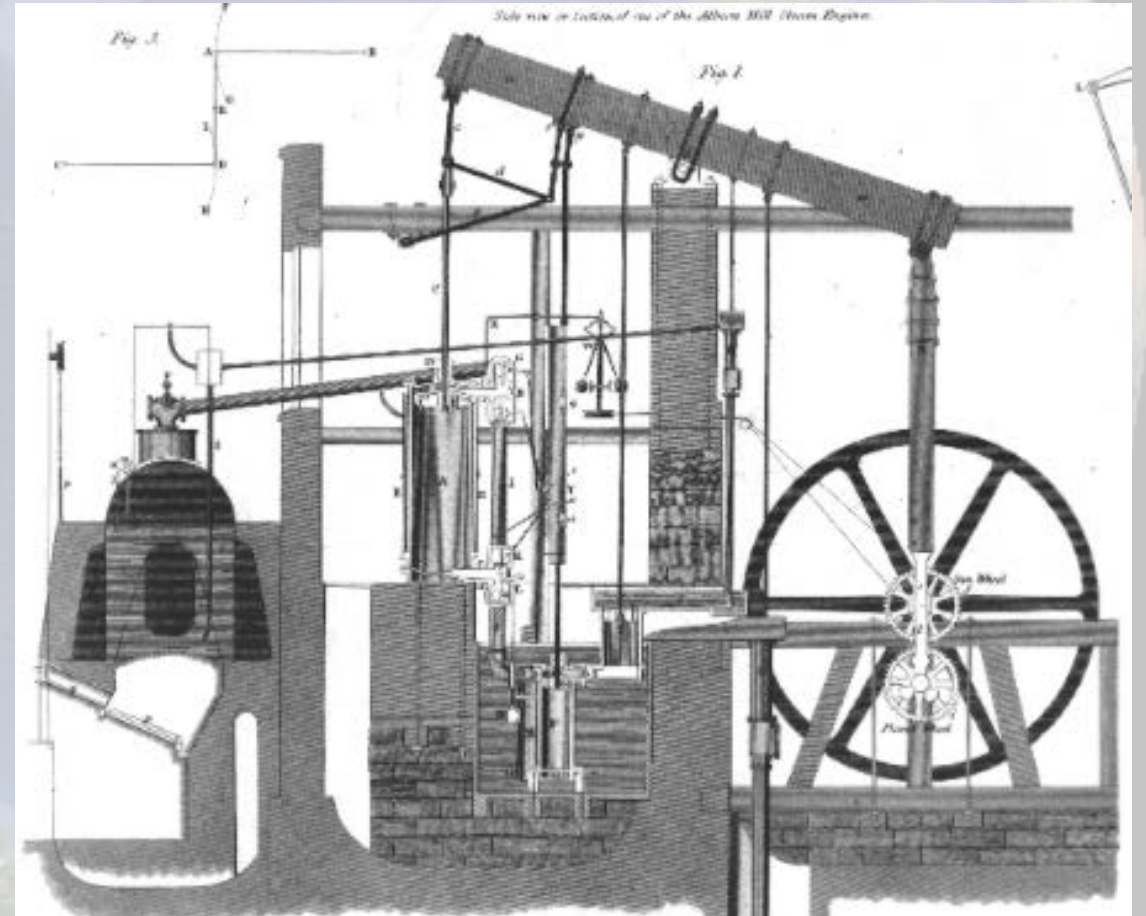
Something more than the sum of its parts.

Consists of three kinds of things:

- elements

- interconnections

- function or purpose



# What is Systems Thinking?

System Thinking first defined in 1987: Barry Richmond

“As interdependency increases, we must learn to learn in a new way. It’s not good enough simply to get smarter and smarter about our particular “piece of the rock.” We must have a common language and framework for sharing our specialized knowledge, expertise and experience with “local experts” from other parts of the web.”



Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

**ScienceDirect**

Procedia Computer Science 44 (2015) 669 – 678

**Procedia**  
Computer Science

2015 Conference on Systems Engineering Research

**A Definition of Systems Thinking: A Systems Approach**

Ross D. Arnold\*, Jon P. Wade

*Stevens Institute, Castle Point on Hudson, Hoboken, NJ 07030, USA*



## What is System Thinking?

- The art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure of a system.
- Takes into account dynamic complexity: change over time and feedback loops (positive and negative).
- Can consider a system a different scales: From farms to molecules

# What is System Thinking?

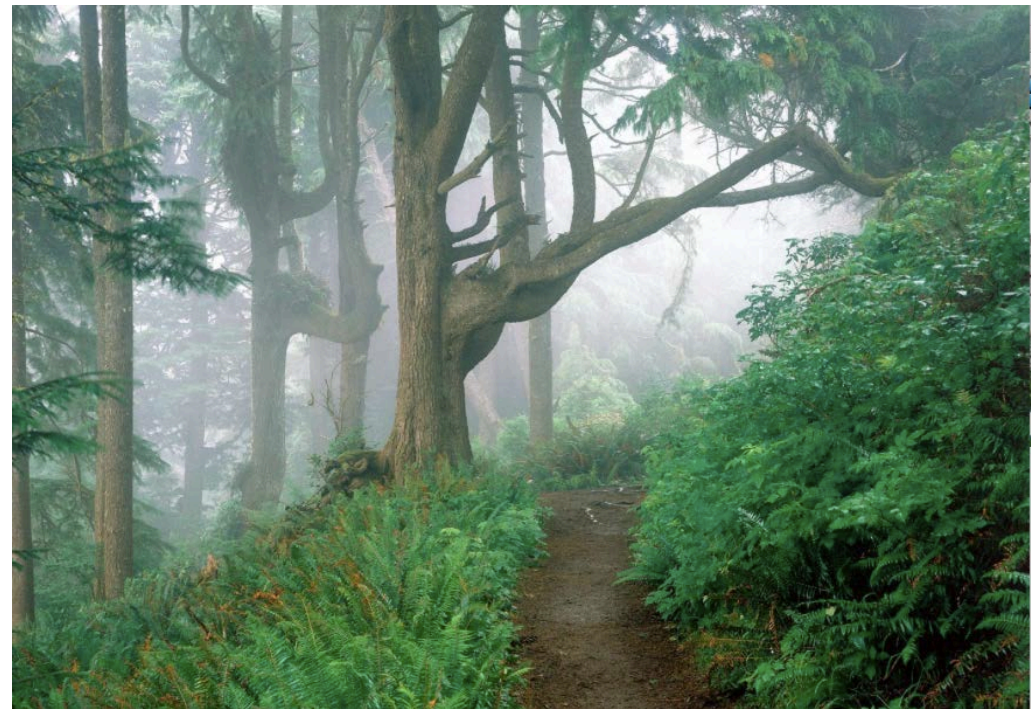
I cannot see the forest for the trees!

A Swedish Proverb



Systems Thinking

I can see the forest AND the trees!





# Support the Full Range of Farmers Needs

## A Comprehensive Approach: From Seed to Sale

### 1. Science and Technology

- Crop improvement
- Crop management
- Discovery science



### 2. Farmer Productivity

- Seeds
- Water management
- Education and training
- Soil health
- Extension



### 3. Market Access

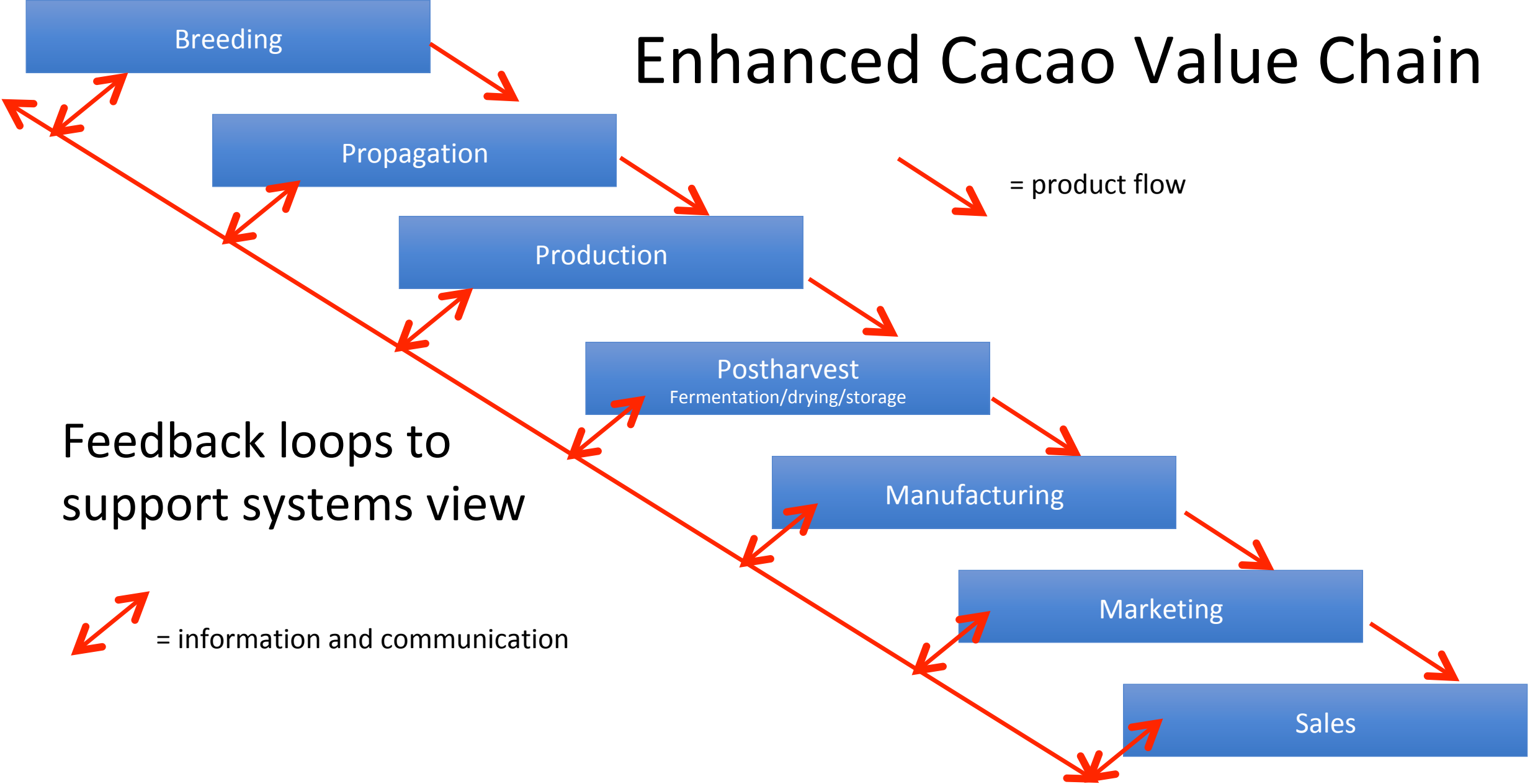
- Access to information
- Access to new and existing markets
- Structured demand



### 4. Policy and Statistics

- Data and statistics
- Research and analysis
- Advocacy and policy change
- Learning and improvement

# Enhanced Cacao Value Chain



Breeding

Propagation

Production

Postharvest

Fermentation/drying/storage

Manufacturing

Marketing

Sales

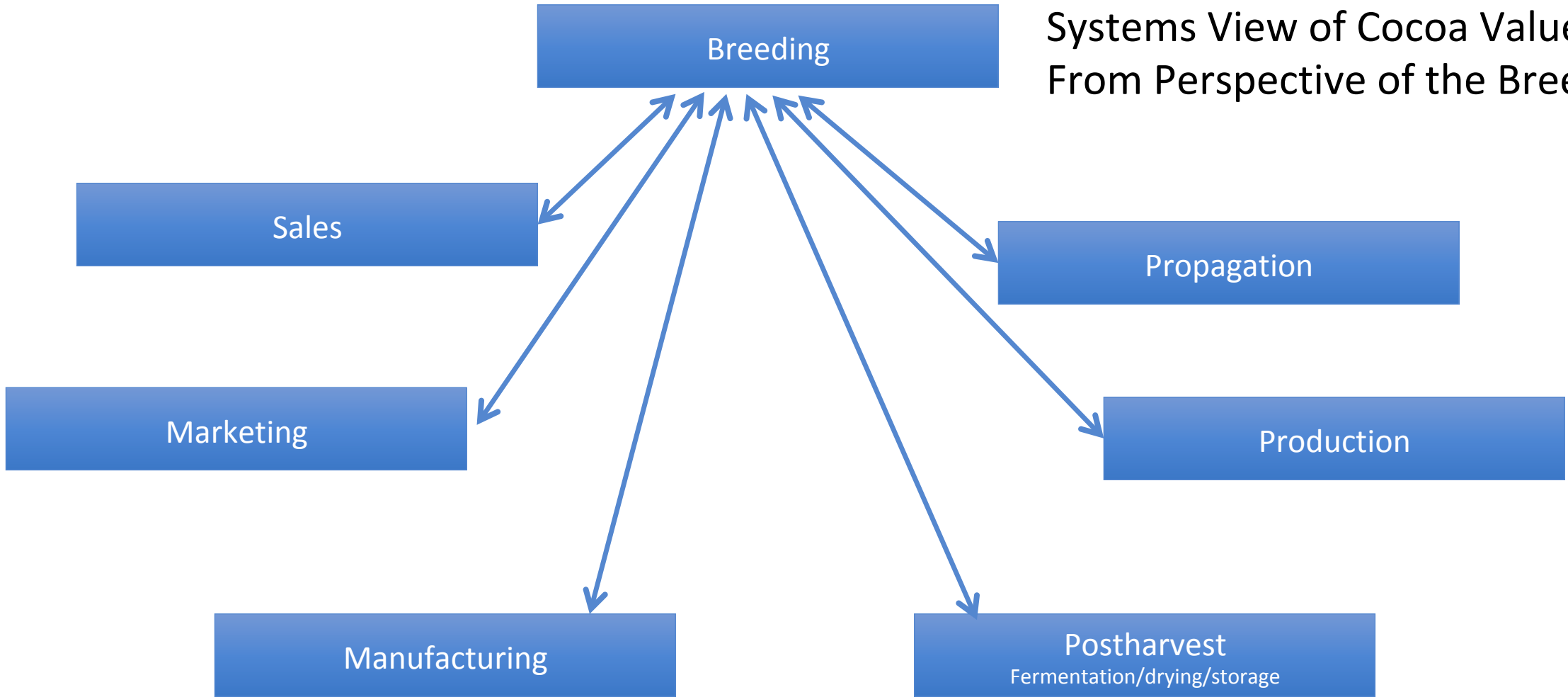
= product flow

Feedback loops to support systems view

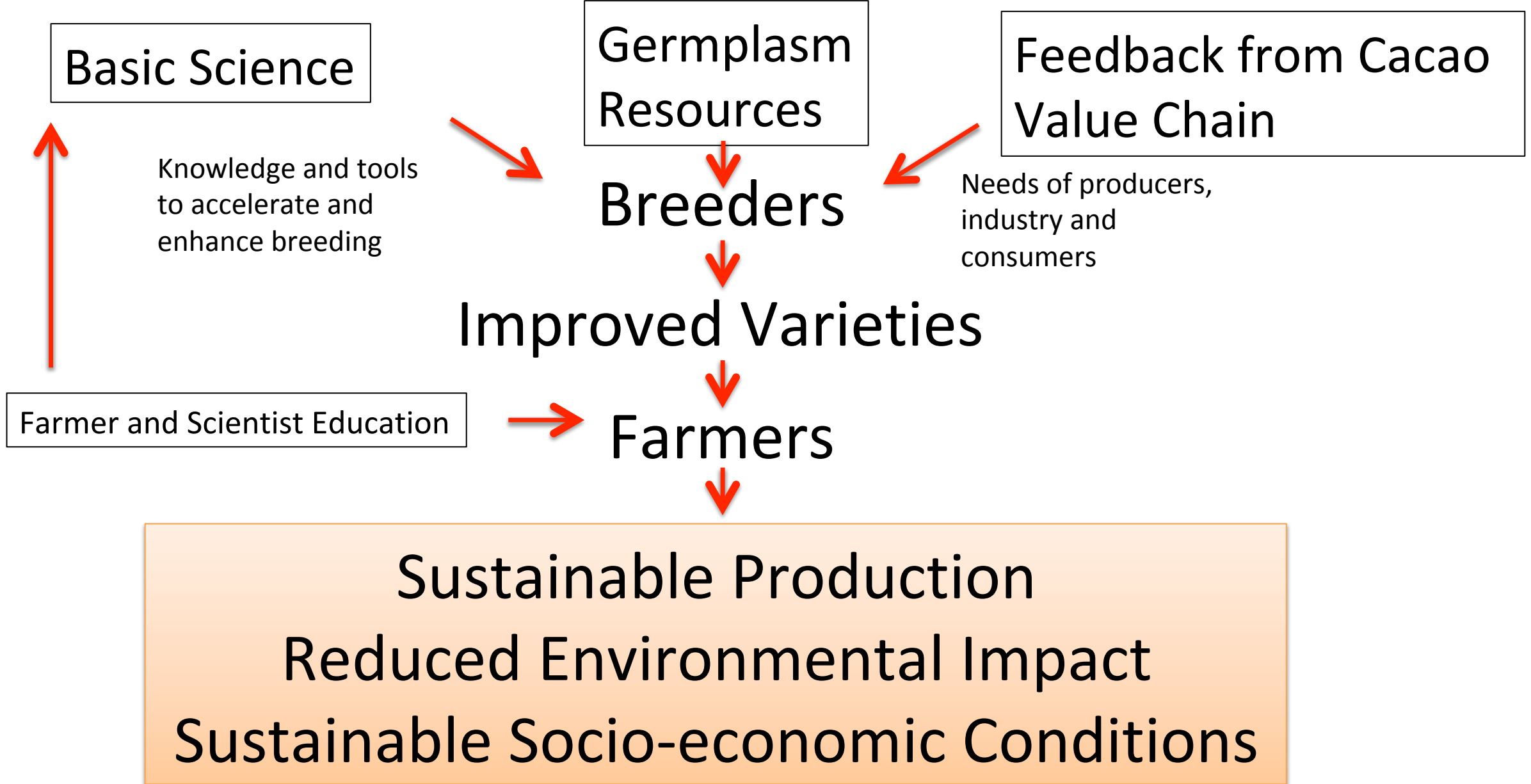
= information and communication



# Systems View of Cocoa Value Chain From Perspective of the Breeder



# Cacao Genetics and Breeding System View





# Role of Basic Science in the Cocoa Value Chain

## Basic Science

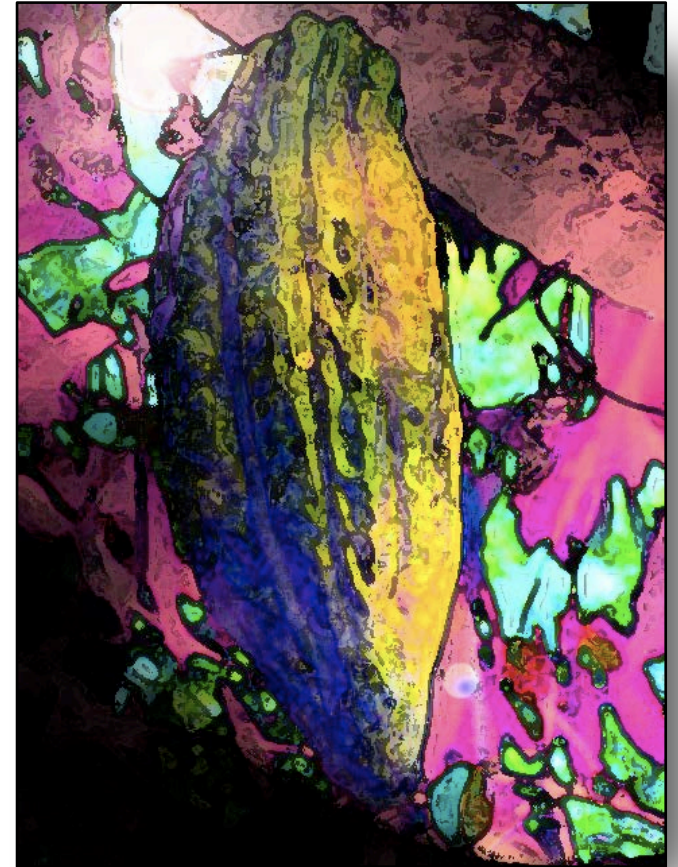
Knowledge and tools  
to accelerate and  
enhance breeding



Breeders



Improved Varieties



# Accelerating Breeding With Basic Science

Identify Candidate Genes for Key Traits via QTL and Association Mapping

Identify Candidate Genes by Translational Biology from Model Plants

Functional Genomics to Understand Mechanisms of Key Traits

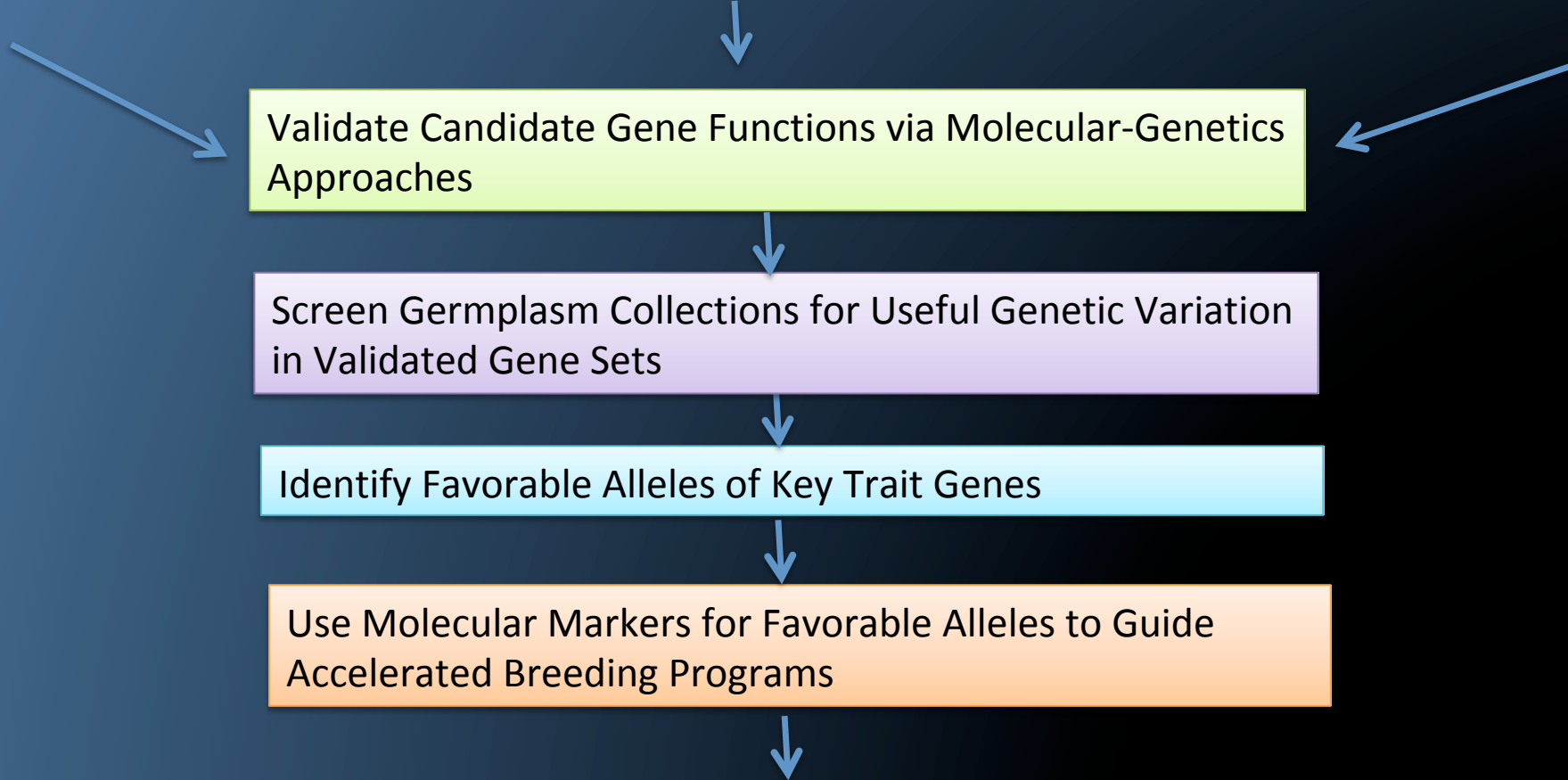
Validate Candidate Gene Functions via Molecular-Genetics Approaches

Screen Germplasm Collections for Useful Genetic Variation in Validated Gene Sets

Identify Favorable Alleles of Key Trait Genes

Use Molecular Markers for Favorable Alleles to Guide Accelerated Breeding Programs

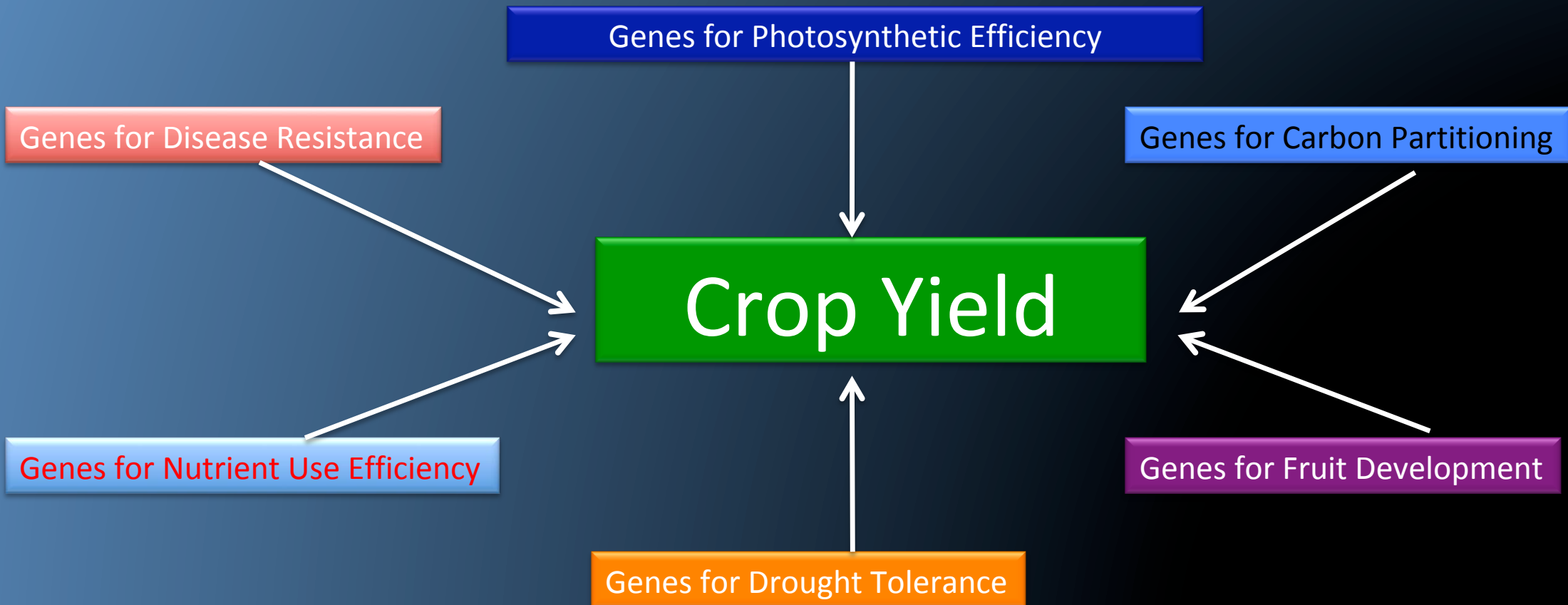
Pyramid Favorable Alleles in New Elite Cacao Genotypes





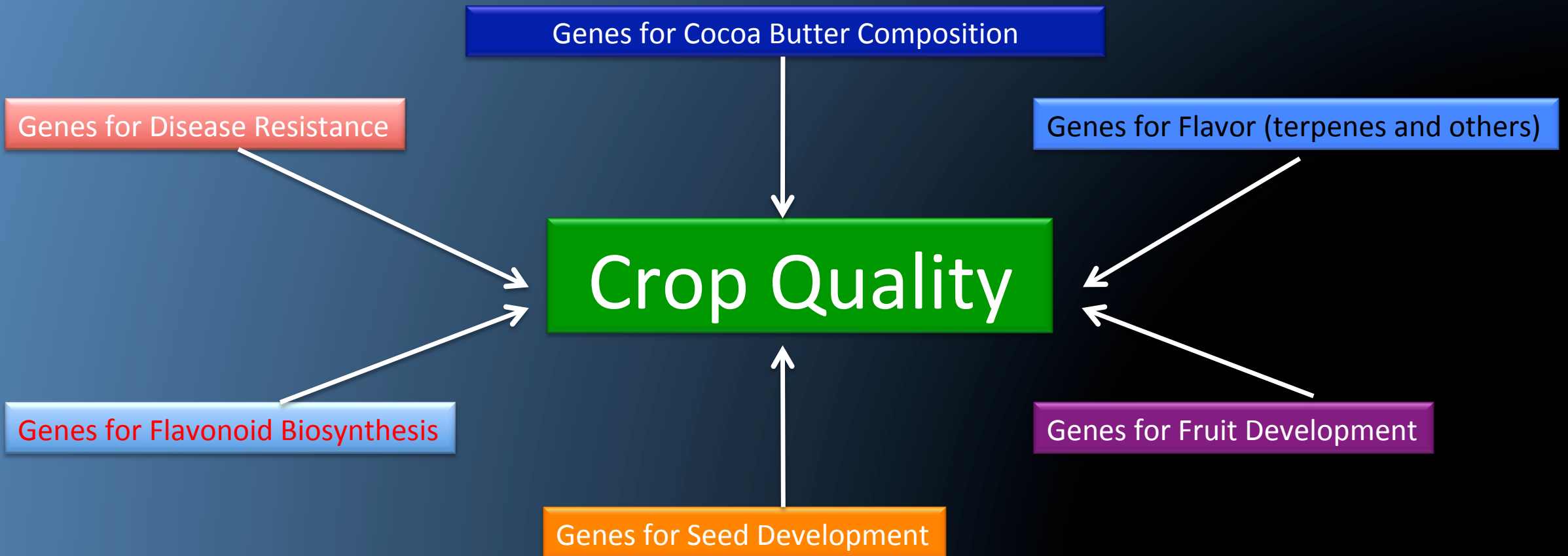
# Gene Discovery

*Most Traits are Controlled by Multiple Genes  
(Multigenic Traits)*



# Gene Discovery

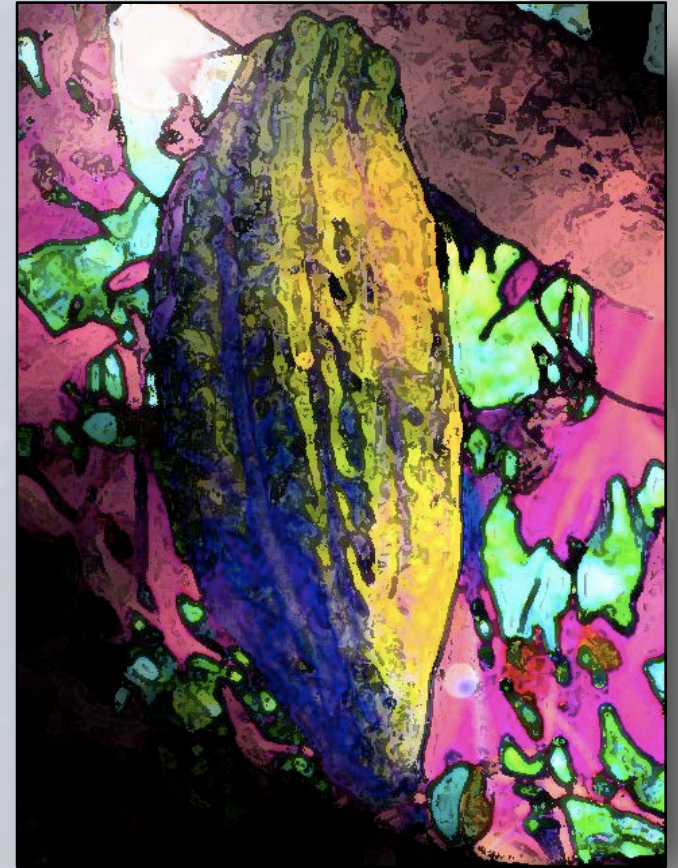
*Most Traits are Controlled by Multiple Genes  
(Multigenic Traits)*





Examples of Molecular Systems View

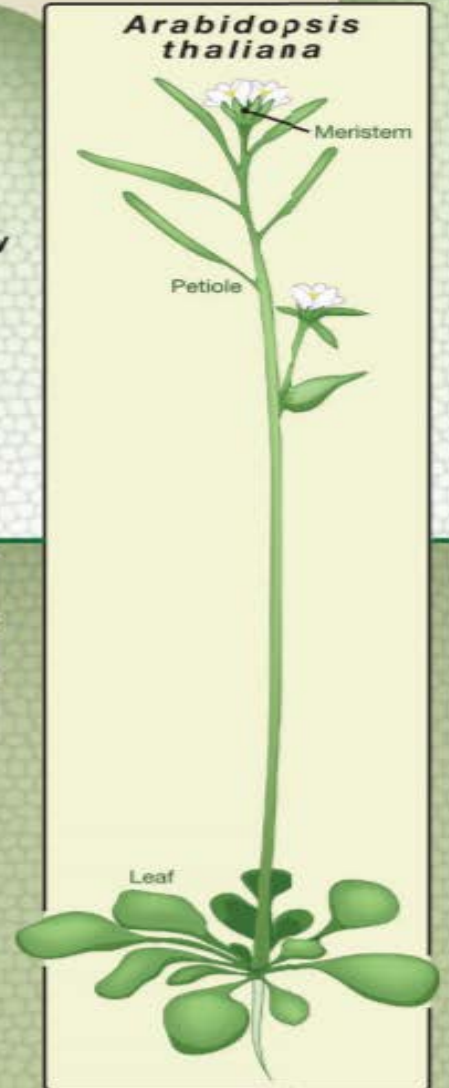
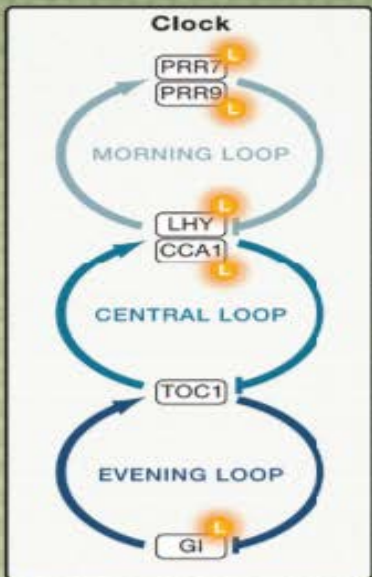
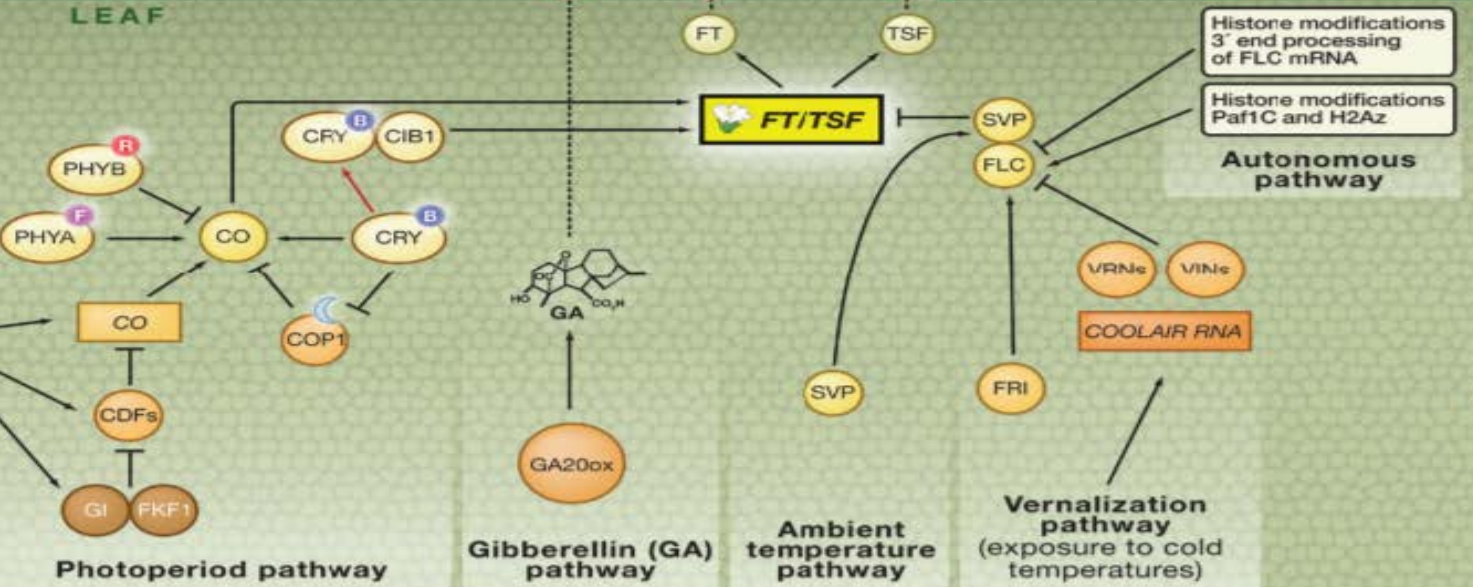
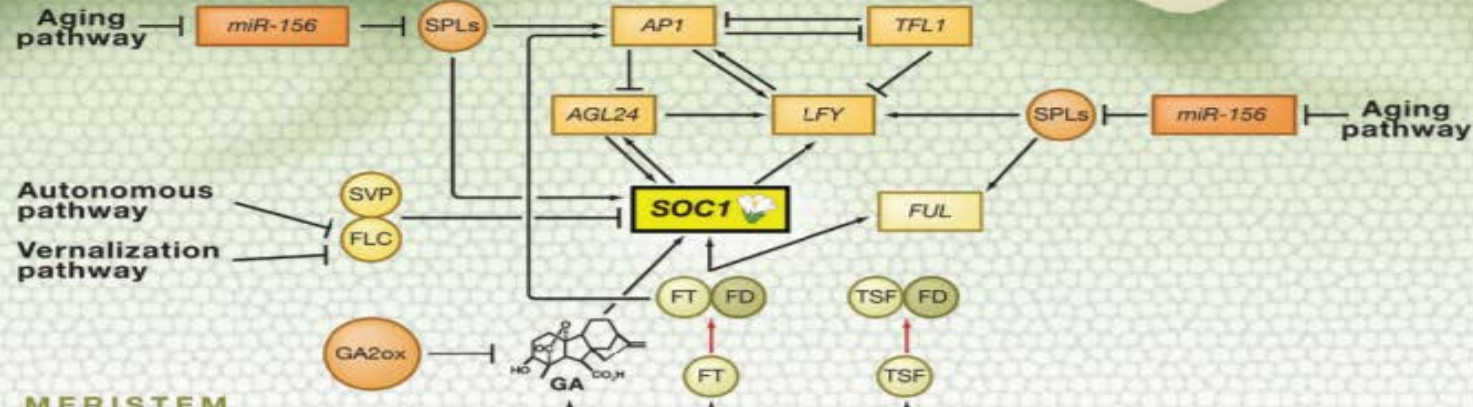
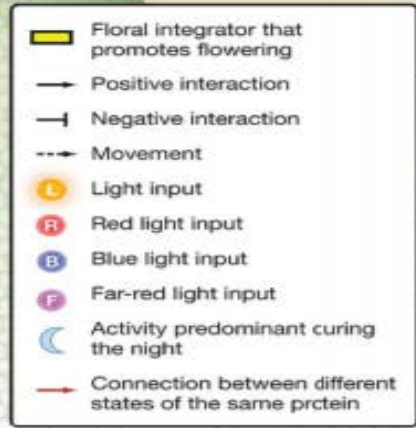
Traits of Importance to Cacao Improvement





# SnapShot: Control of Flowering in *Arabidopsis*

Fabio Fornara, Amaury de Montaigu, and George Coupland  
 Max Planck Institute for Plant Breeding Research, Köln 50829, Germany



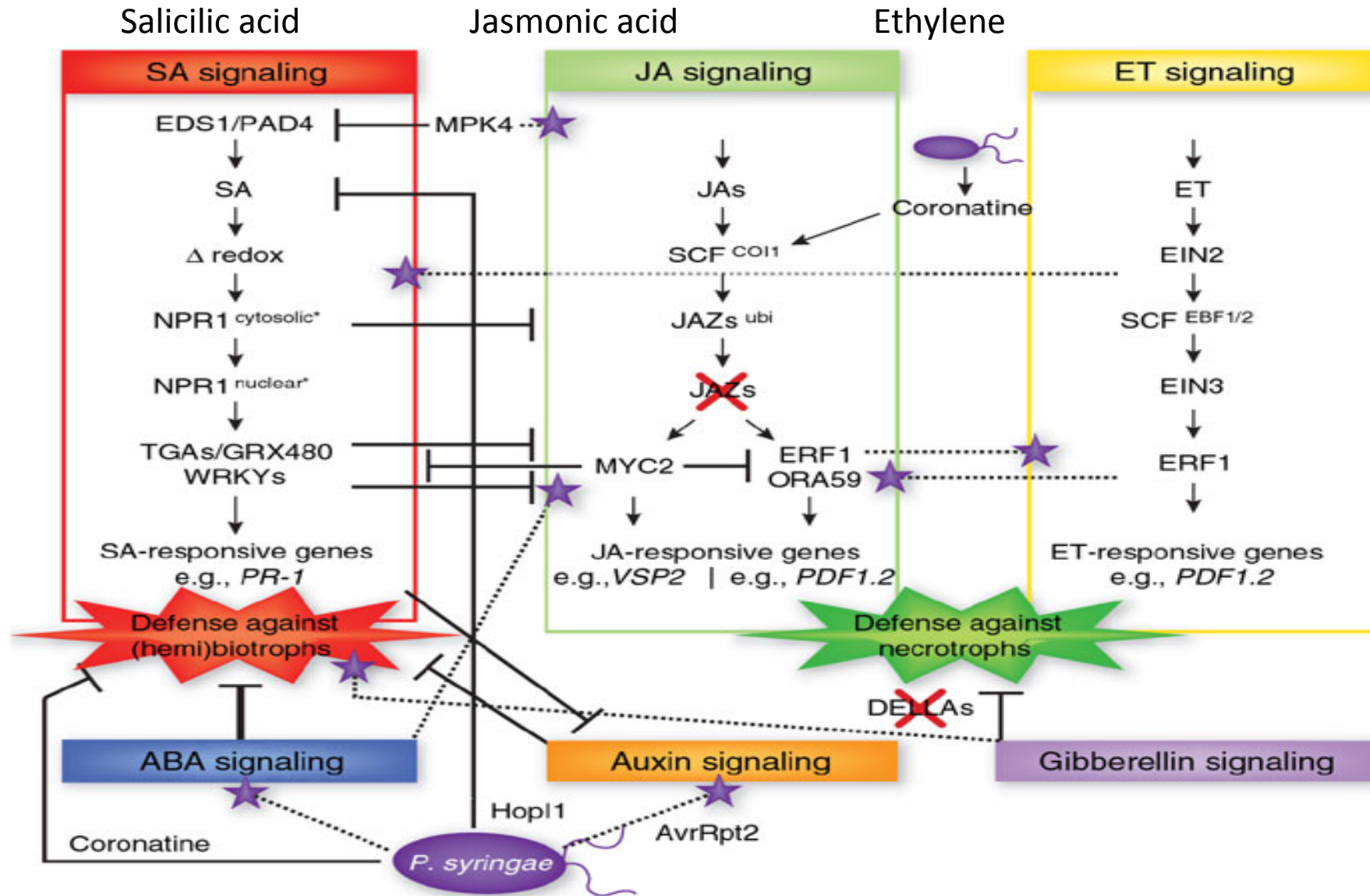




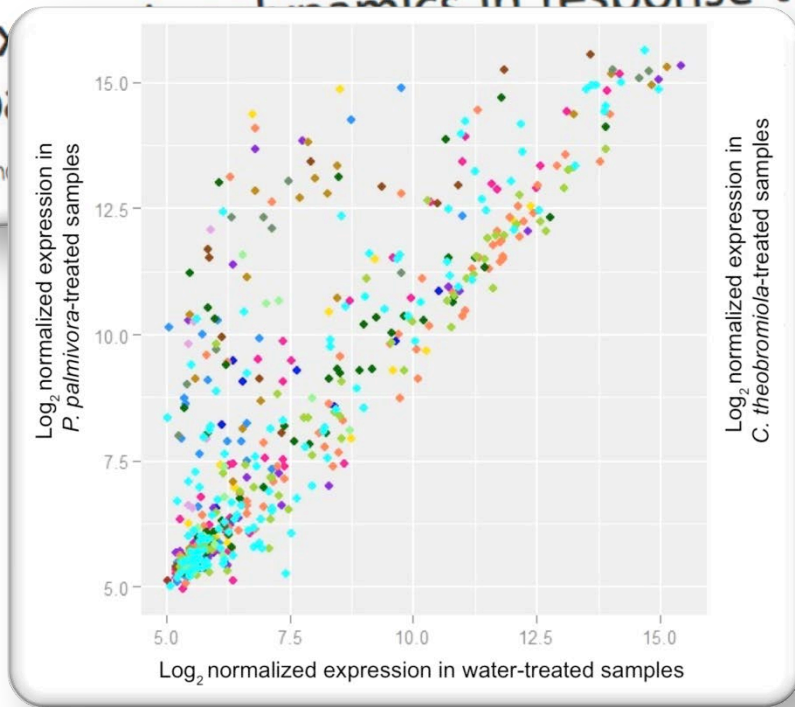


# The Principles of Plant Immunity

## Signal Transduction

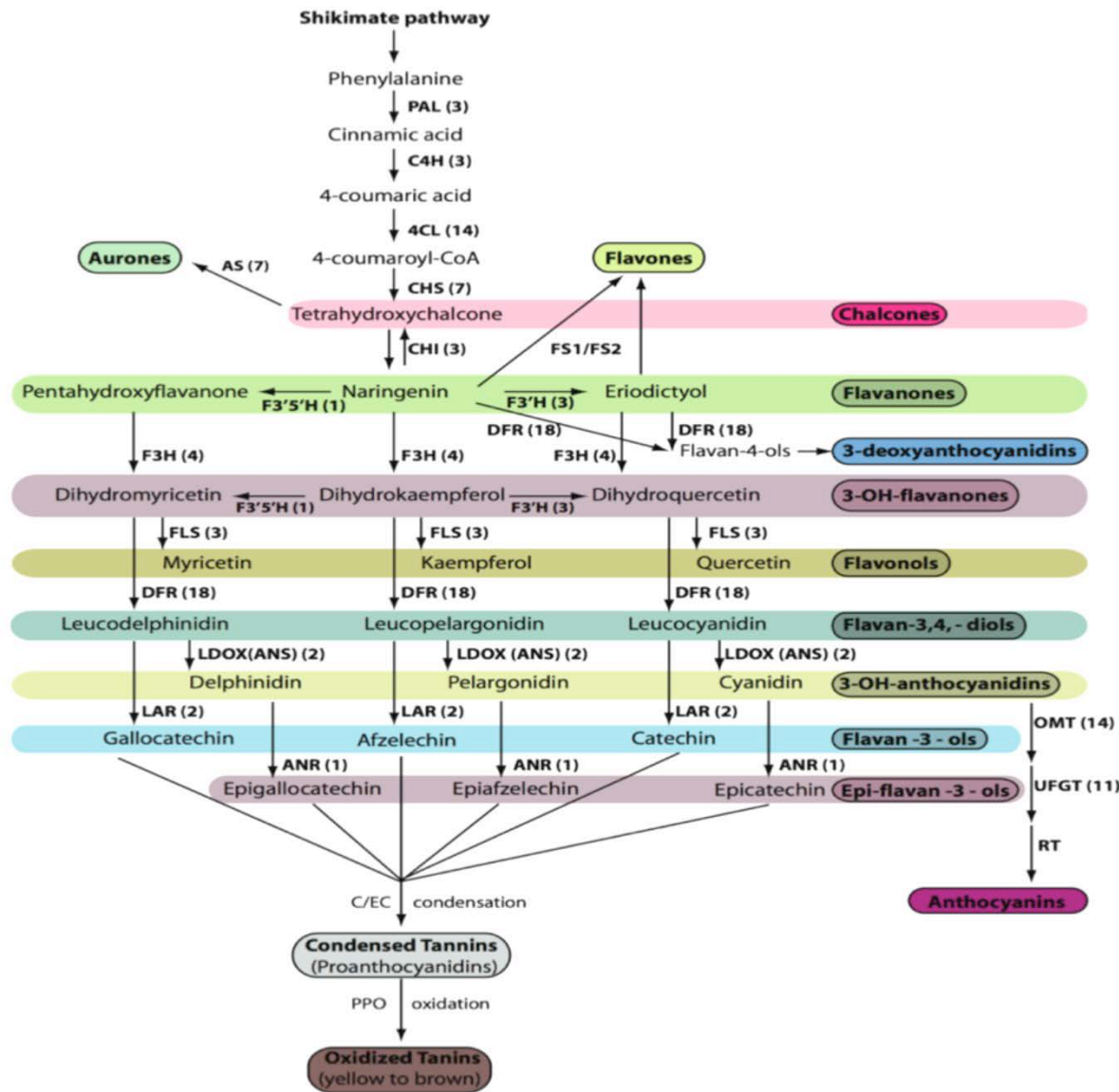
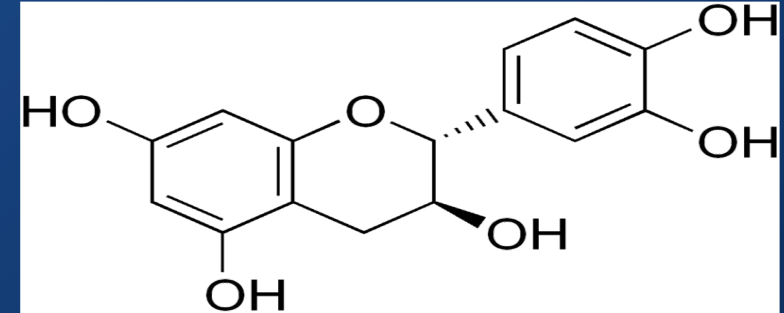


# Andrew Fister



- ### Identified and Annotated All Cacao PR Genes
- 359 genes
  - 45 Chitinases genes in 4 Multi-gene families
  - Complex gene expression profiles
  - Complex transcriptional response to *Phytophthora* infection

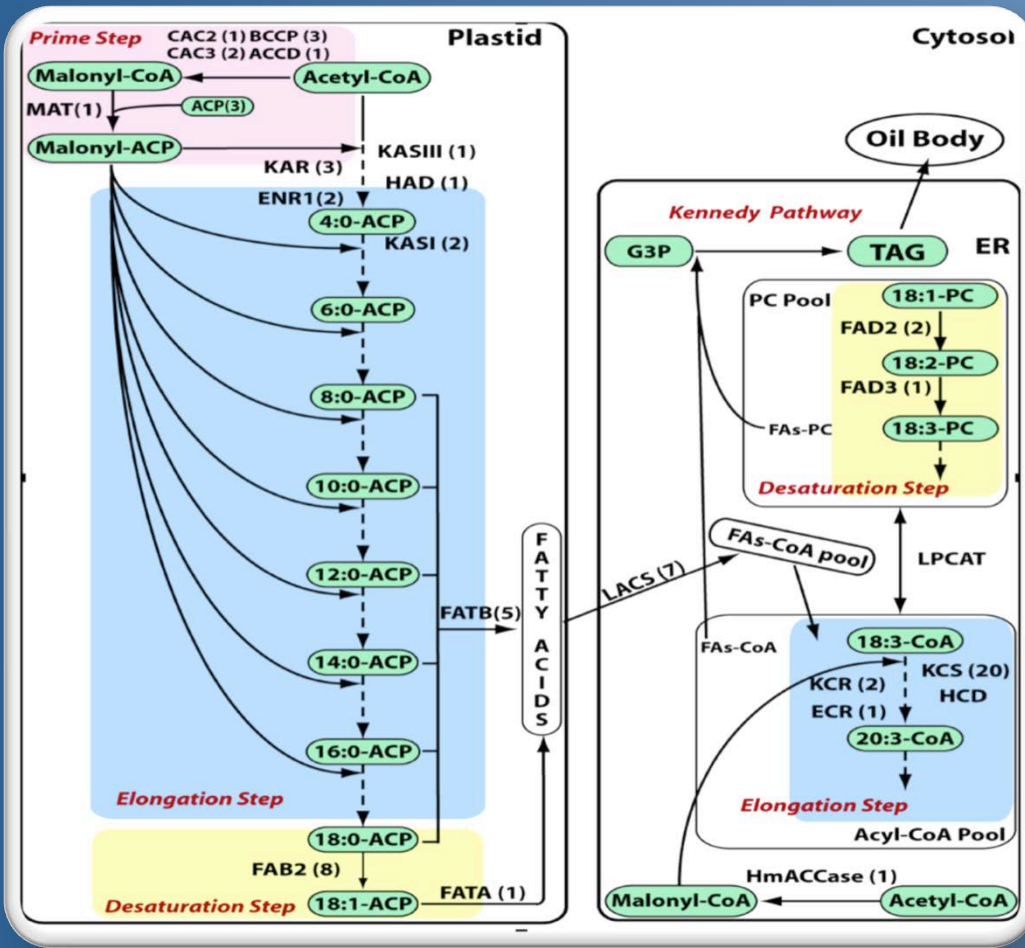
# Flavonoid Biosynthesis



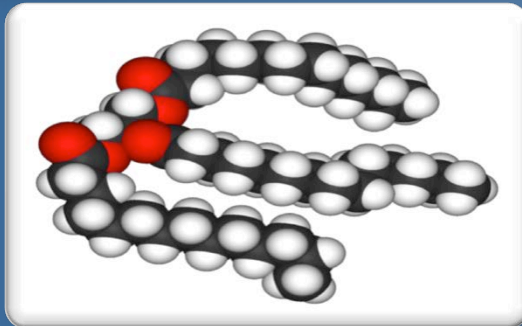
- 32 Genes
- No Expansion of Cacao Gene Copy Numbers
- Myb Box Transcription Factor Regulators



# Cocoa Butter Biosynthesis



27 Enzymes  
 75 Genes  
 13 single copy genes  
 Family sizes up to 20



Plant Science



Accelerated Breeding



Improved Crop Varieties



Increased Farm Productivity and Income



Sustainable Cocoa Supply



Reduced Environmental Impact

How Will *Systems Approaches* Lead to Helping Farmers and a Sustainable Cocoa Supply?

# How to Incorporate Systems Thinking Into Your Work

- Design interdisciplinary research into your projects and work with collaborators out of your field
- Read literature out of your field
- Learn about Systems Thinking and the Science of Team Science
- Teach Systems Thinking to your students



Thanks for your Attention

Questions?



CCN51, Ecuador Photo: M. Gultinan