Genetic resources (and their use) in *Coffea canephora*

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Genetic resources and their use in *Coffea canephora*

Dr Christophe Montagnon

“ Dear coffee friends, I would like to thank the organization committee of this important conference for their kind invitation. I thought I could come but reasons beyond my control forced me to cancel my trip to Brazil. I deeply regret it as I know there are so many good friends of mine in this room. Among them, I would like to mention Dr Koffi N’Goran, from Côte d’Ivoire where part of my heart belongs and where I’ve learned so many things on *Coffea canephora*. I want to thank Pierre for having accepted to present my talk. If there is any question or doubts after presentation, please feel free to send me an email (on the slide) and I’ll be more than happy to answer ”

christophe.montagnon@cirad.fr

Background

- Importance of *Coffea canephora* (CC)
  - Growing share against Arabica (25 → 35 %)
  - Soluble industry
  - Biological meaning for arabica coffee
- Importance of breeding
  - Crucial factor for productivity and quality
  - Farmers shall benefit from the genetic progress
- Importance of genetic resources (GR)
  - What do we know about CC-GR?
  - Optimal use ?

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Content of the presentation

- CC within the *Coffea* Genus
- CC natural / wild genetic diversity
  - Natural area of distribution
  - Surveys, Maintenance, Description
- Access to CC genetic resources
- Use of CC genetic resources
- Conclusions and perspectives

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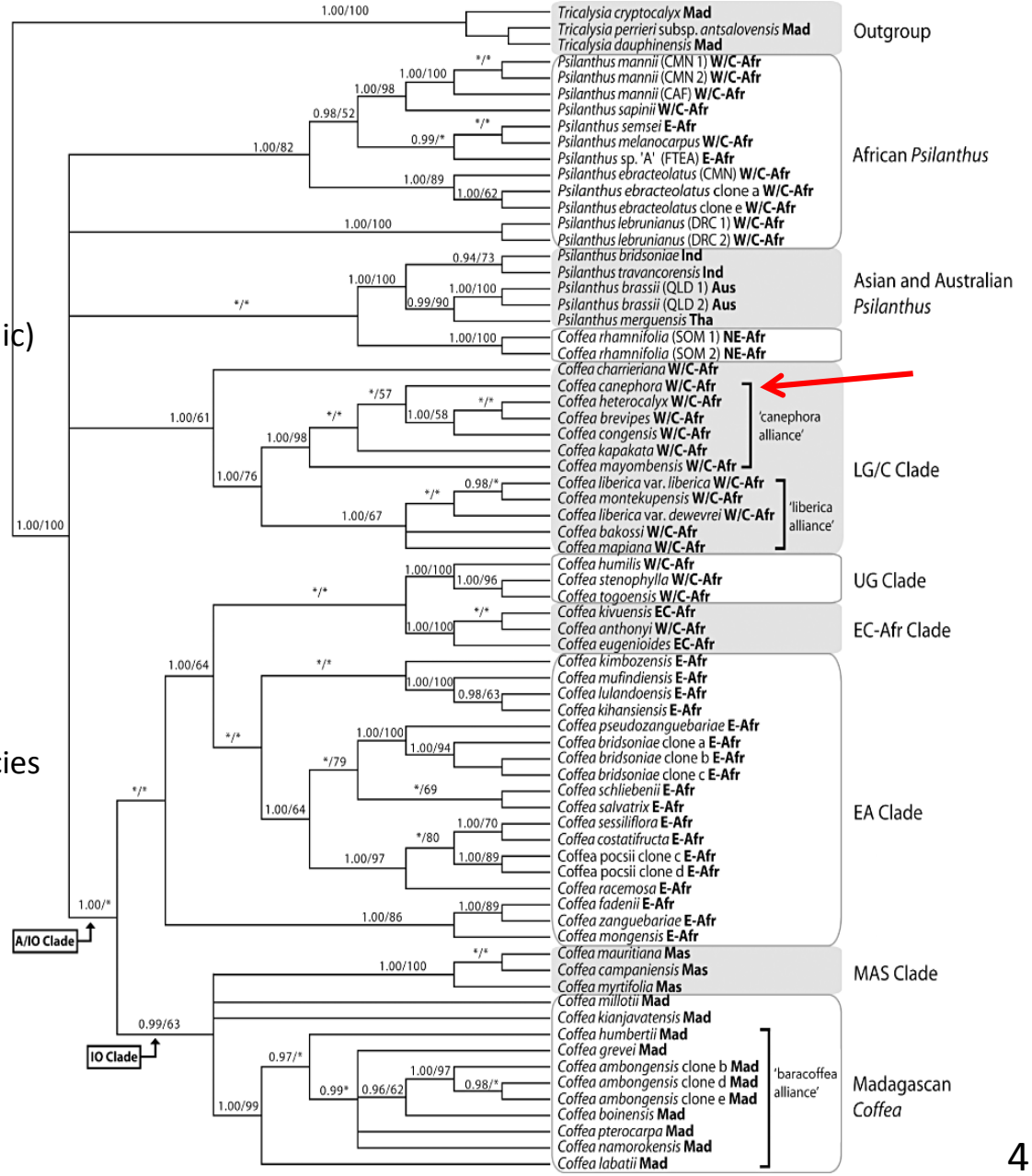
C. canephora within the big *Coffea* genus

(Davis *et al*, 2011- Botanical Journal of the Linnaean Society 167 : 357-77.)

- ***Coffea***:
  - more than 100 species
  - *Psilanthus* subsumed to *Coffea*
  - Structuration in several clades (geographic)

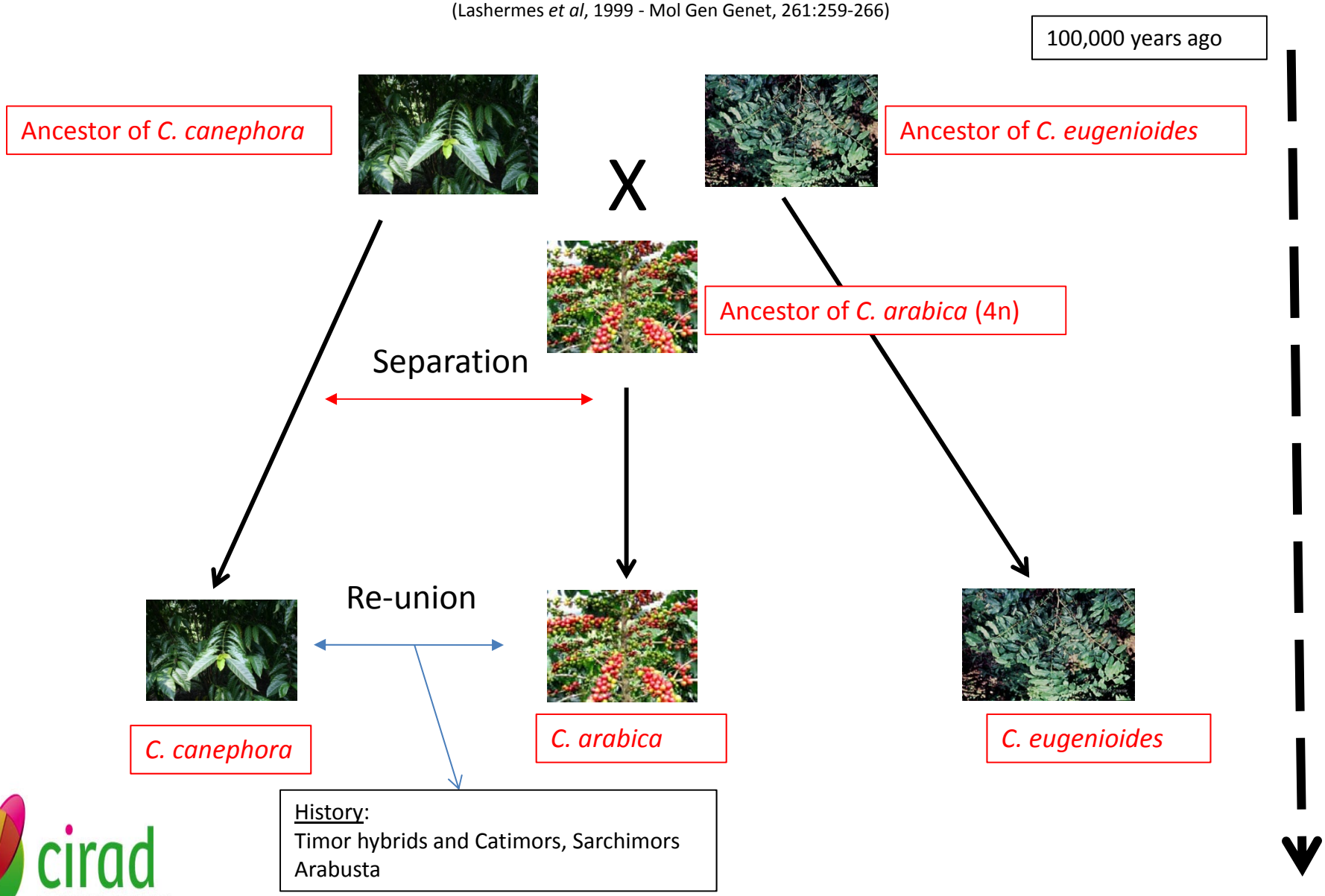
- ***C. canephora*** :
  - LG/C Clade = Lower Guinea/Congolian
  - 'Canephora alliance' together with:
    - C. brevipes
    - C. congensis
    - …
  - Easy to inter-cross with most Coffea species

Combined plastid–internal transcribed spacer (ITS) (Davis *et al*, 2011)



Ancestor of *C. canephora* : Progenitor of *C. arabica*

(Lashermes *et al*, 1999 - Mol Gen Genet, 261:259-266)



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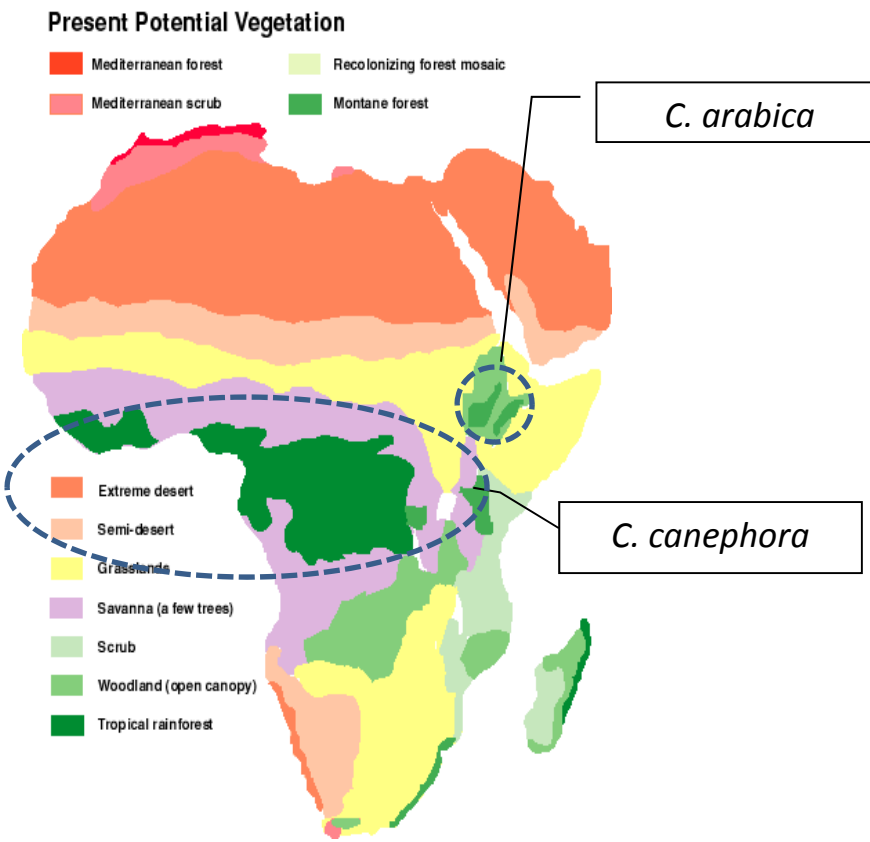
Geographical origin and natural populations of *CC*



Natural distribution area = Africa

- *C. canephora* :
  - from Guinea to Uganda
  - From Centrafrican Republic to Angola

Much larger than:

- *C. arabica* : = Ethiopia + Southern Sudan

Fragmented :Western + Central Africa + Uganda

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Geographical origin and natural populations of *CC*

- Natural population size: from few to hundreds of trees in a delimited area
- Distance between natural populations: few hundred meters to several kms
- Dissemination of pollen
  - Insects
  - Wind
  - Several kilometers in some occasion
- Dissemination of seeds = mostly zoochory (>100km)
  - Birds
  - Small mammals
  - Apes
  - Elephant
  - Man !

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Genetic diversity of wild *CC* populations

- **Survey**
- **Maintain**
- **Describe**

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Genetic diversity of wild *CC* populations: **Survey**

Year	Surveyed Countries	Organisms	Where in field collection	Reference
1975-1991	Côte d'Ivoire	IRCC ORSTOM	Côte d'Ivoire	Berthaud, 1986 Le Pierres (Rapport) Couturon et Montagnon, 1991 (Rapport)
1975	Centrafrican Republic	IRCC	Centrafrican Republic Côte d'Ivoire	Berthaud et Guillaumet, 1978
1983	Cameroon	IRCC ORSTOM	Cameroon Côte d'Ivoire	Anthony *et al.*, 1984
1985	Congo (Brazza)	ORSTOM	Congo (Brazza) Côte d'Ivoire	De Namur *et al.*, 1988
1987	Guinée	IRCC ORSTOM	Guinée Côte d'Ivoire	Le Pierres *et al.*, 1990
2005-2008	Ouganda	Cirad–Uganda	Ouganda	Musoli *et al.*, 2009

A lot of international efforts…But less since the 80's…

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Genetic diversity of wild *CC* populations: **Survey**

- Further surveys to put on the agenda.
  - Funds needed
  - But cost of doing nothing ?

- Priority = Gabon, Angola, RDC

- Maybe some national initiatives we are not aware of…Important to know…

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Genetic diversity of wild *CC* populations **Maintain**

- ***In situ*** **:**
  - Genetic erosion with deforestation
  - Farmers plantations = important opportunity !
- **Field collection : Côte d'Ivoire / French Guyana / Private initiatives**
  - Genetic erosion 3 % per year
  - Climatic events
  - Political disrupt
- ***In vitro***
  - Costly
  - Genetic erosion
  - Genetic stability ?

Cryopreservation (storage at liquid nitrogen temperature, -196°C)– Dussert *et al*, 1998- Seed Science Research (1998), 8 : pp 9-15)

Cost effective - Really needs to be considered (Dulloo et al, 2009- Crop Science Vol. 49 No. 6, p. 2123-2138)

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Genetic diversity of wild *CC* populations **Maintain**

- Maintaining genetic resources is not an easy task !!!
- Definitely to be put on the agenda
- Support currently set field collections
- Maybe with an international mandate ?

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Genetic diversity of wild *CC* populations: **Describe**

- Describing is different from Evaluating
  - Describing is neutral / Evaluating gives a value (selection criteria)
  - Value is subjective and can vary with time and space
  - Describing is not only through molecular markers
  - Environment stable morphological descriptors are useful

- Description is a serious issue, not to be neglected. Only way to make further use of genetic resources

- Description shall be stored an made available in databases: not that difficult but time consuming and has a cost

- Makes sense to implement and manage description data together with field collection curators

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Genetic diversity of wild *C. canephora* populations:

Describe

WHAT DO WE KNOW ?

Structuration of the genetic diversity of *CC* populations

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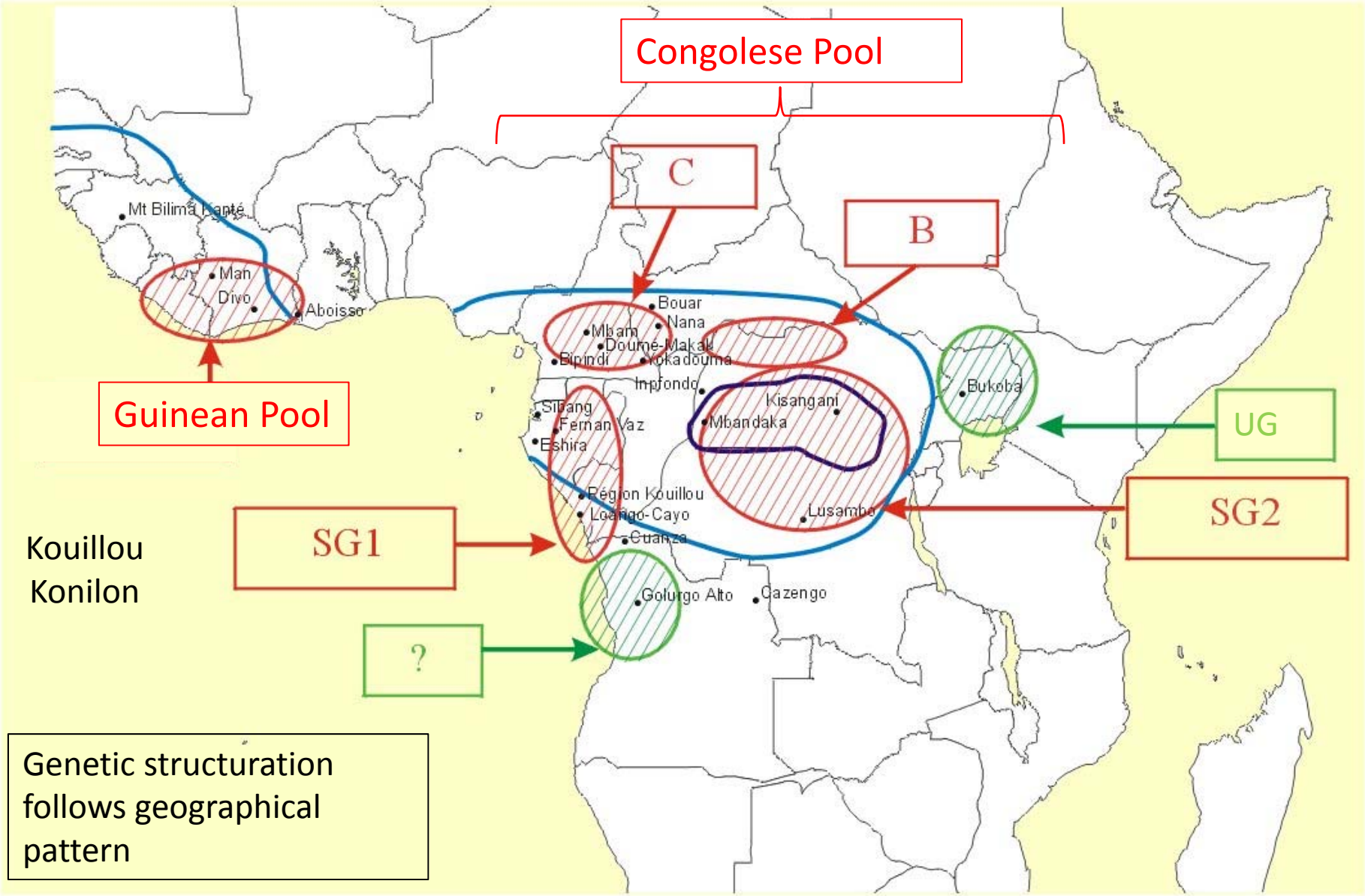


Main *C. canephora* genetic groups and historic location of survey

- An important genetic diversity

Berthaud (isozymes)

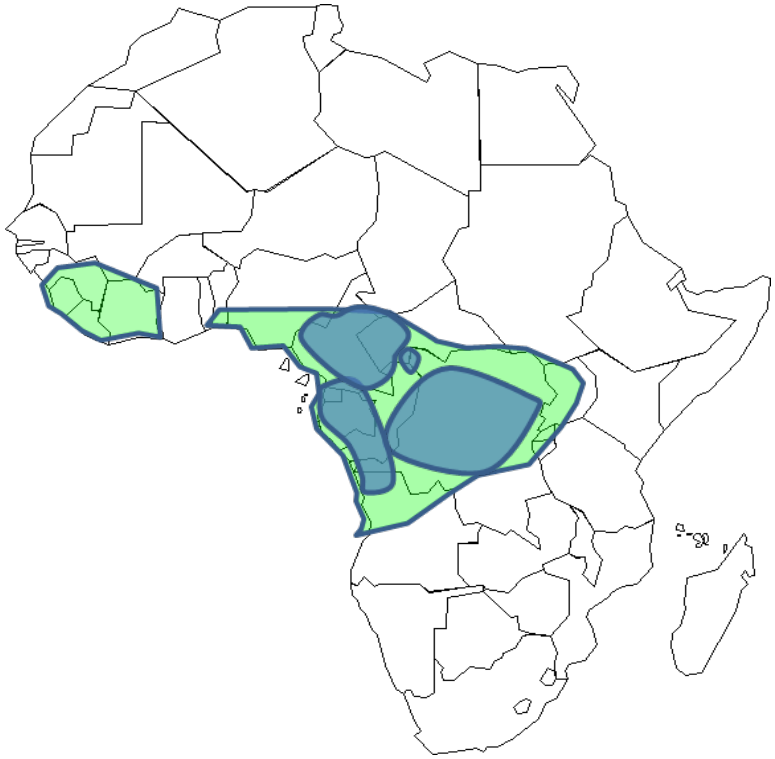
G	C

Montagnon *et al.*, (isozymes)

G	SG1	SG2

Dussert *et al.*, (RFLP)

G	SG1	SG2	B	C



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Genetic diversity of wild *CC* populations: **Describe**

WHAT DO WE KNOW ?

Structuration of the genetic diversity of *CC* populations

- Large genetic diversity
- One homogenous Guinean Pool + a sub-structured Congolese Pool
- Strong structure
- Ideal situation in plant breeding for taking advantage of heterosis ?
- Depends on actual access to Genetic Resources and what Genetic Resources…

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Actual access to Genetic Resources of *CC*

What kind of Genetic Resources ?

- Complex and different situations
- Important to speak the same languages
- Definitions…

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Actual access to Genetic Resources of *CC*
Few definitions – P_0, P_1 and P_n

- **P_0** : Wild populations or locally domesticated populations from wild populations (landraces)
  - Represents the local natural genetic group
  - No mix with other groups

- **P_1** : Individuals originating from a cross between two different P_0.
  - Roughly similar to a F1 as a breeder concept
  - Might be a controlled or natural cross between a local and an introduced P_0 in plantations or field collection
  - Highly heterozygous

- **P_n** : Any population originating from one or several generation of any P_1 intercross
  - Roughly similar to recombining population as a breeder concept
  - Might be a controlled or natural cross between different P_1 in plantations or field collection
  - Genealogy hard to trace back (*CC* : strictly outcrossing species)
  - Genetic richness depending on the genetic groups represented by P_0 founders (parents of involved P_1)

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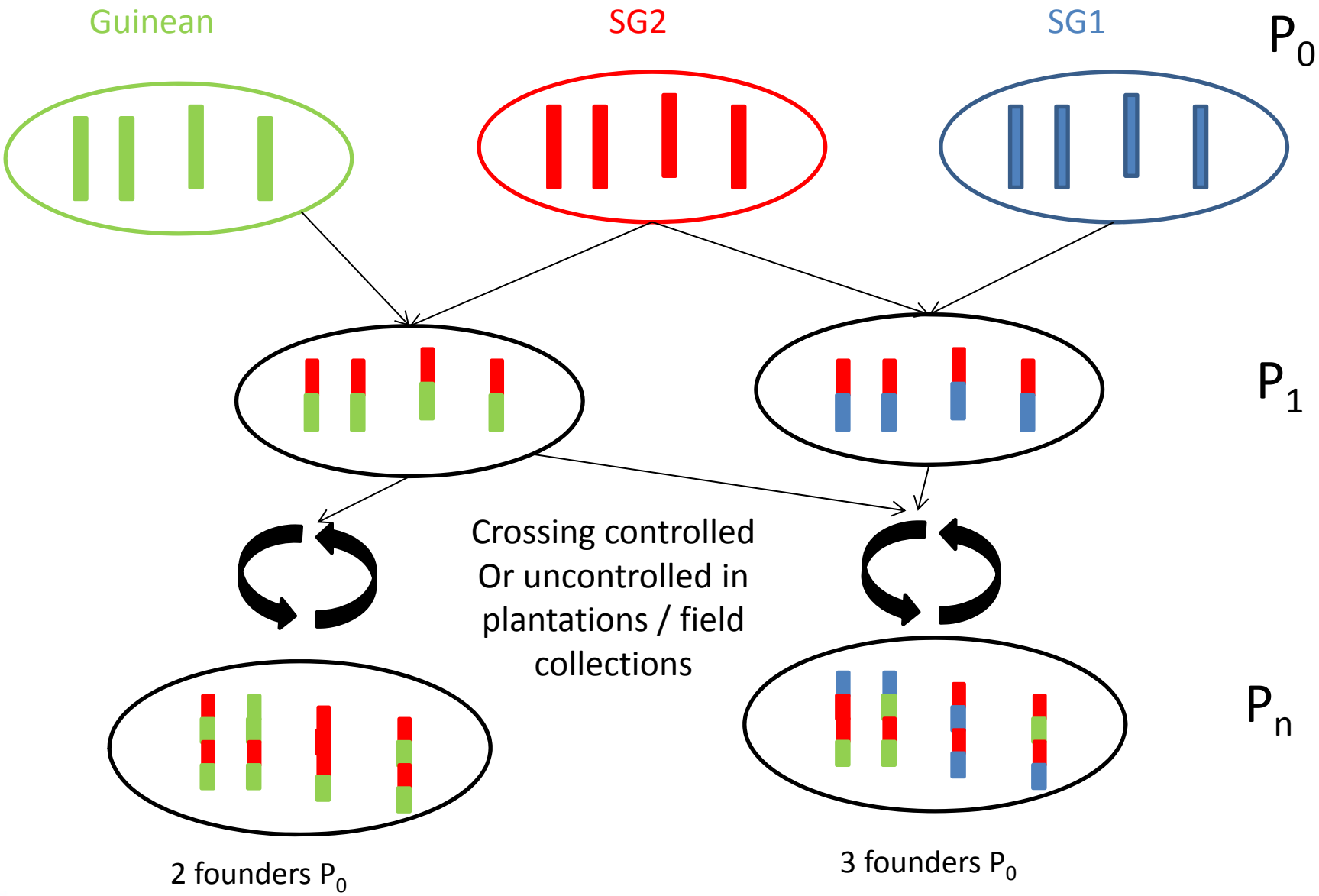

Note: virtually impossible to rebuilt separated P_0 from P_1 or P_n

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Actual access to Genetic Resources of *CC*
How they have traveled and inter-mixed?

Two main channels

- <u>Major one= Early farmers exchanging material between countries</u>
  - Exchanging P_0
  - As a consequence:
    - Different introduced cultivated P_0 in the same plantation
    - Introduced P_0 cultivated nearby local P_0
  - As a result:
    - Intercrossing between different P_0
    - First generation of P_1
    - Local replanting with some P_1 and then P_n
    - Next seeds exchange with a distance farmer = P1 or P_n
    - And so on…
  - Original P_0 are lost
  - Almost no traceability : only try to deduce genetic origins from observed present genetic pattern
- <u>Minor one = Traceable institutional exchange between countries or private initiatives</u>
  - Populations in field collections
  - Maintenance across the years (or decades) ?

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?

P_0

- Have P_0 of different genetic origin been introduced in my country ?
  - I do not know
  - I assume so but I have no traceability. It was not under institutional control.
  - Yes but it was mostly only one single genetic origin P_0
  - Yes P_0 from different genetic origins and they are well maintained in field collections

Most cases

Brazil

Côte d'Ivoire: very complete
French Guyana: quite complete
Nestlé CCC: supposedly complete

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?

P_1 and P_n

- I have or have had in the past a strong and well referenced breeding scheme and/or introduction strategy so that I can trace back my crosses from original P_0 . Plantations are mostly planted with my selected varieties.

Brazil, Vietnam (?)

- Same but my varieties were not massively adopted, so that cultivated material is quite different from what I can offer from my breeding programs.
  - Either because informal introduction channels
  - Or because seeds are re-used without control
  - Or both…

Côte d'Ivoire + former Main Breeding Centers (Indonesia, Madagascar, Uganda…)

- I do not know

Most cases

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?

In few words…

- Available genetic resources:
  - Under control in research stations
  - *In situ* in national coffee plantations (often neglected)
- Knowledge about genetic resources
  - Mostly quite weak if not absent
  - --> Needs a deep genotyping analysis to know what is the warehouse !!!

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Actual access to Genetic Resources of *CC*

What is my local genetic availability?

Some contrasted situations…

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?
Some contrasted situations…

Côte d'Ivoire

- Well referenced and complete field collections
- All genetic origins but no wild Ugandan (UW)
- Well referenced breeding programs with P_1 varieties from Guinean and Congolese P_0
- Most part of cultivated material represents P_n mostly originating from Guinean, SG2 and SG1 original P_0 (Montagnon et al, 1993 *Café Cacao Thé*, **37** (2) : 115-119)

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?
Some contrasted situations…

Brazil

- Well referenced field collections
- Mostly one origin (SG1)
- Well referenced breeding programs
- Most part of cultivated material is the selected varieties

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?
Some contrasted situations…

Mexico

- Well referenced but small field collections
- Well referenced breeding programs (Romex)
- No published available information on the corresponding genetic diversity
- Most part of cultivated material is not composed of selected varieties
- Preliminary study on cultivated material = One homogeneous P_n involving mainly SG2 and some SG1 alleles not that far from a SG2 P_0. Apparently no Guinean alleles. (Montagnon, unpublished data).

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Actual access to Genetic Resources of *CC*
What is my local genetic availability?
Some contrasted situations…

Ecuador

- Well referenced but small field collections
- Well referenced breeding programs
- No published available information on the corresponding genetic diversity
- Most part of cultivated material is not composed of selected varieties
- Preliminary study on cultivated material = two P_0 SG1 and SG2. Apparently no Guinean alleles. (Leroy & Loor, unpublished data).
- Hypothesis: Contrasted ecosystems - Selection of SG1 and SG2 types in dry and humid areas, respectively.

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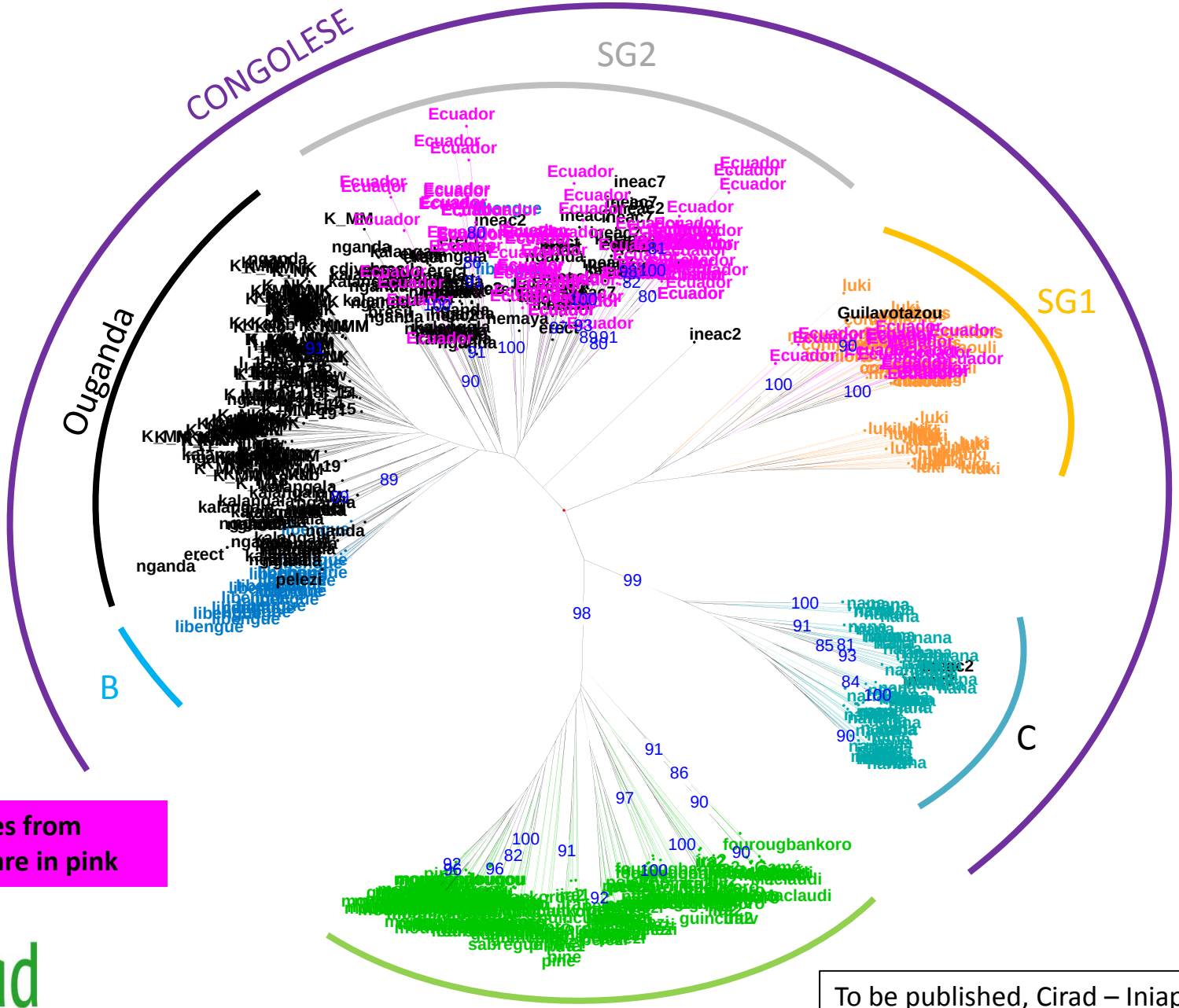
Genetic diversity within *C. canephora* genotypes from Ecuador



Genotypes from Ecuador are in pink

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To be published, Cirad – Iniap collaboration – T. Leroy & G. Rey Loor

Actual access to Genetic Resources of *CC*
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Closing the Genetic Diversity and Resources **description**

Opening the optimal **use** of Available Genetic Resources

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Few words on breeding theories

- The Graal of any breeder is Genetic Diversity
- Let's consider two contrasted situations:
  - Breeder have access to distinct P_0 Populations
  - Breeder have only access to P_n populations

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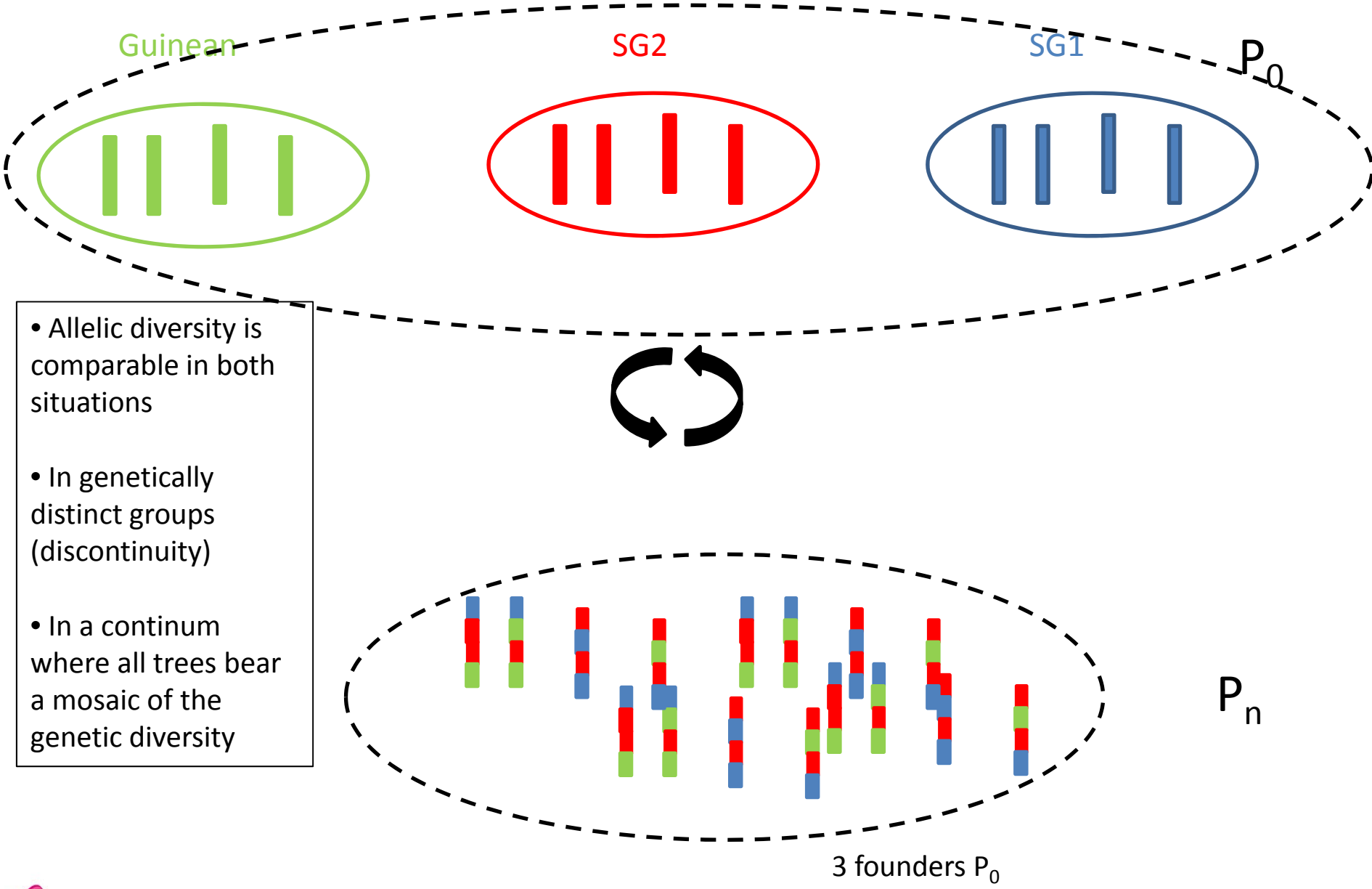

- Allelic diversity is comparable in both situations
- In genetically distinct groups (discontinuity)
- In a continum where all trees bear a mosaic of the genetic diversity

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"Available P_0" situation

Heterosis = hybrid vigor : offspring is superior to both parents

Parents shall be:
- *Genetically distant*
- complementary traits

→Belongs to different **heterotic groups**

Are CC P_0 heterotic groups ?

- Guinean and congolese groups are heterotic (Leroy et al, 1993. Euphytica 67:113-25.)
  eg: G x SG1 or G x SG2
- Congolese groups btw themselves:
  - low heterosis for SG1 x SG2 (in Côte d'Ivoire conditions)
  - to be tested for other groups combinations

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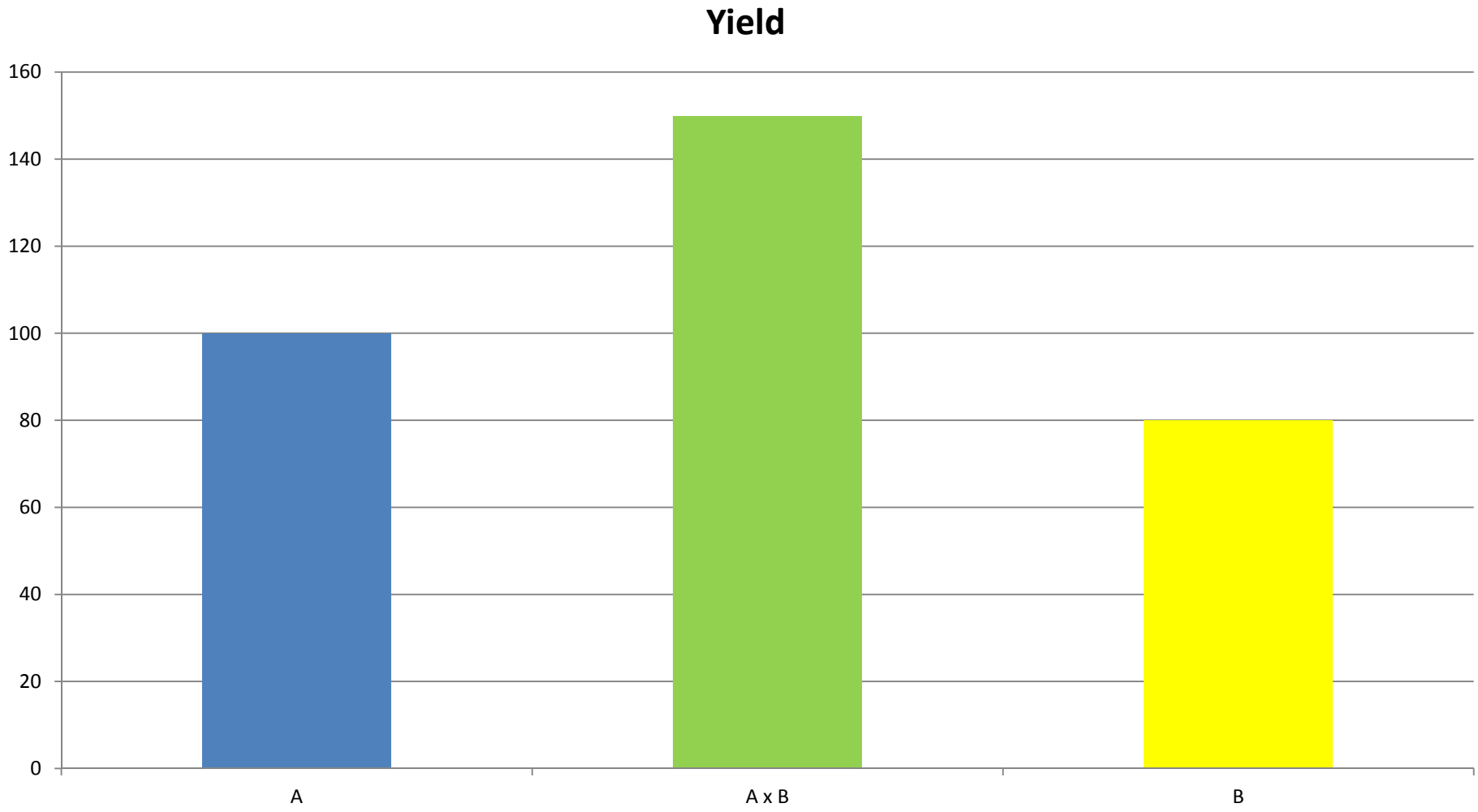

Heterosis: AxB is better than either A or B

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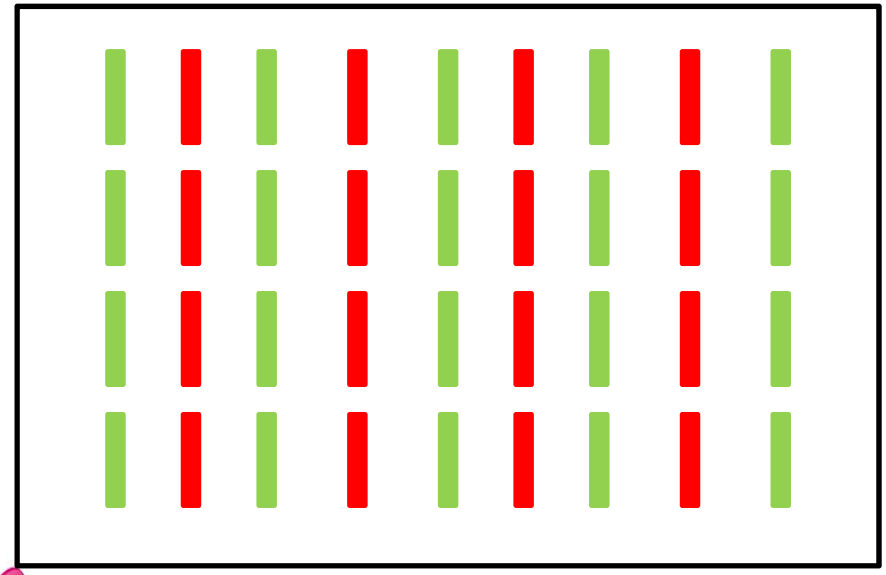
“Available P_0” situation – Strategy (Côte d’Ivoire)

Guinean SG2

Homogeneous G x SG2 hybrid (= P_1) progeny

Yield (100 basis) 60 100 140

Possible long term strategy: Reciprocal Recurrent Selection



- Isolated **seed** garden with both G and SG2 parents
- All seeds are the G x SG2 hybrid (due to CC being strictly outcrossing)
- Easy and cost effective to mass produce
- Seed material easy to transport and manage in large or small farmer nurseries

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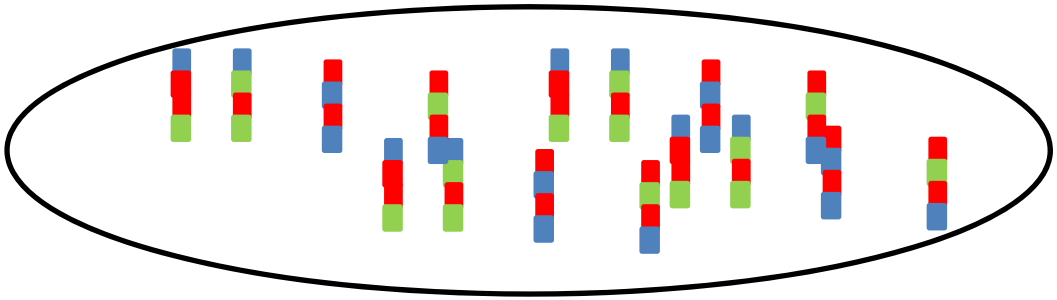
“Available P_n” situation



- No heterotic groups → Hybrids are not better than the best parent
- Possible **cloning** of outstanding trees (possible vegetative multiplication of *CC*)
- Rapidly fixing genetic progress (out of thousands of trees in plantations for instance)
- Possible long term strategy through classical recurrent selection
- Mass production
  - Horticultural: cutting gardens
  - *In vitro* somatic embryogenesis: Vitro-plants
- Cuttings or Vitro-plants:
  - not that easy to mass produce (as compared to seeds)
  - not that easy to transport and manage by farmers

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So… Seeds or clones ???

- Not that clear cut, **not exclusive** strategies
  - Clones in seed strategy: Might think of cloning best trees within "P_1" progenies BUT Cost and time consuming for questionable genetic

Except for certain specific situations, I choose Access to P0 and intergroup seed strategy.

r

- strategy
  - If you have access only to P_n, then rapidly fix genetic progress through clones while introducing P_0 populations
  - If you have access to both:
    - Put more weight on P_0 / seed strategy on the long term
    - Put more weight on P_n strategies (at least in the short term) if you have a specific constraint you want to address: specific quality, CWD resistance…easier to fix through cloning.

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Conclusions / Perspectives

What was not part of the presentation

- Marker Assisted Selection:
  - genetic diversity is needed
  - Important results (Leroy *et al.*, 2011- TGG)
  - Not really the scope of this very presentation
  - My opinion: prepare for it but a lot of genetic progress can still be achieved through classical breeding

- Selected varieties:
  - Scope of the presentation more on pre-competitive Genetic Resources
  - Great available varieties:
    - Côte d'Ivoire (Hybrids)
    - Uganda (clones with tolerance to CWD)
    - Brazil of course
    - Mexico (Romex)
    - ….
  - What about their actual use ?
    - Very low impact / most present cultivated *CC* coffees are not selected varieties (but Brazil/Vietnam)
    - Question of professionalization of the coffee seed sector

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Conclusions / Perspectives

Take home message

- **CC genetic diversity of CC**
  - So rich, So useful….while….So unequal the access to
  - So many lost opportunities of genetic progress for the farmers
  - So little knowledge about local availability: Genotype and further genotype !!!
  - No comprehensive breeding strategy if no optimal use of Genetic Diversity

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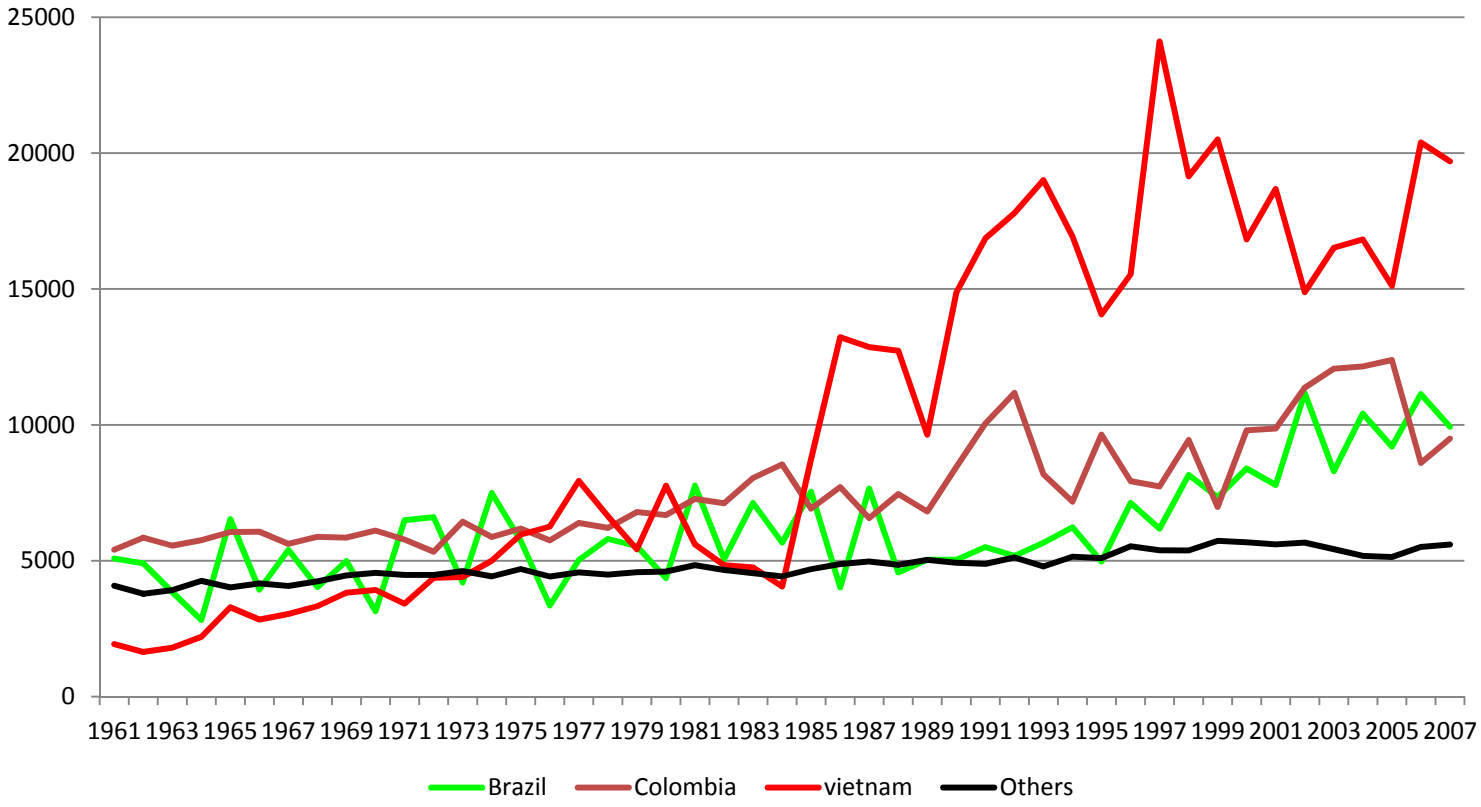
Trends in coffee production

Evolution of Yield (Hg green coffee / Ha) since 1961: Brazil, Colombia, Vietnam *vs.* others (FAO)



Three countries account for general increase in yield, especially VN (2 t gc / Ha)
All others, on average, are at 1961 levels of productivity

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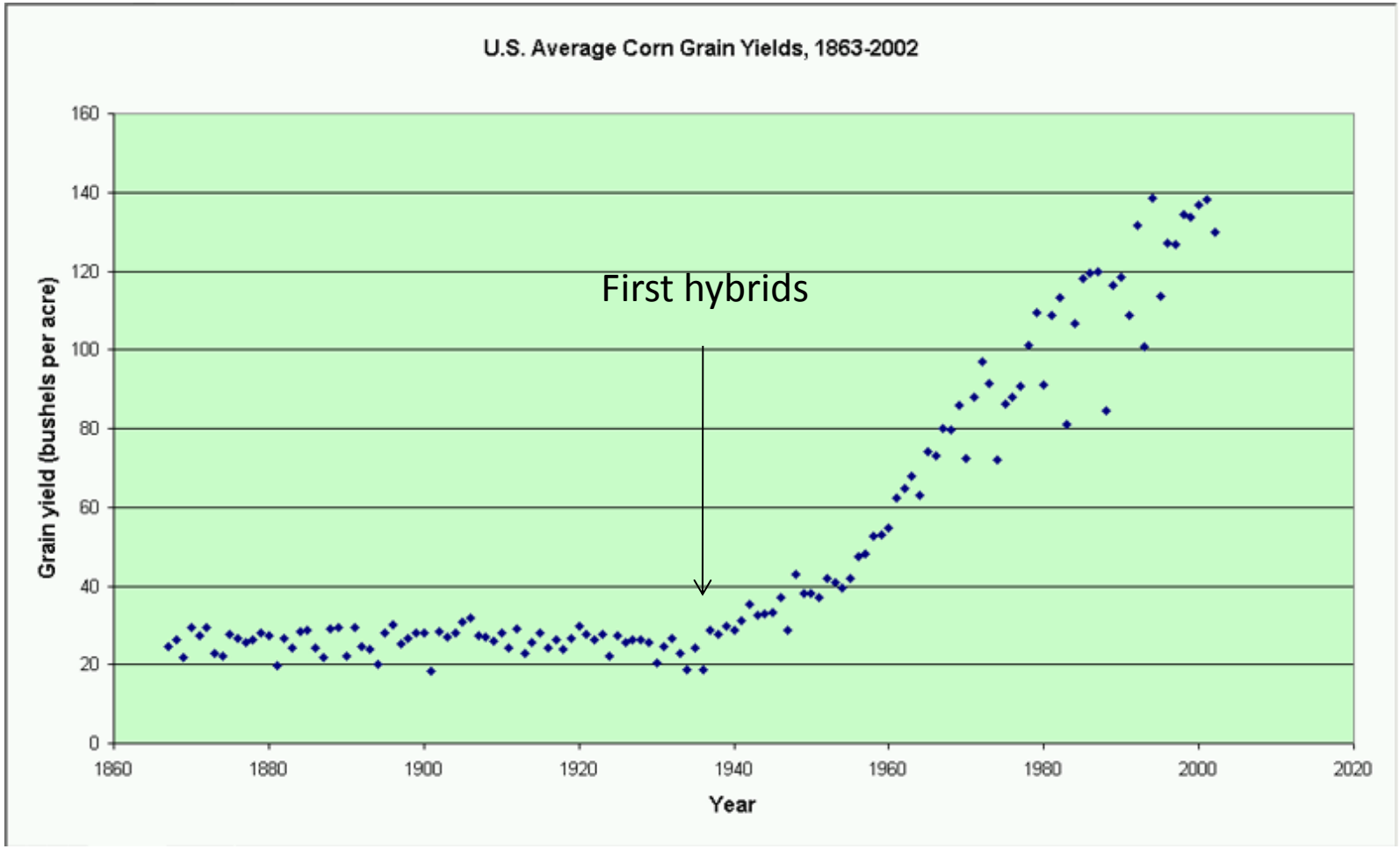
Benchmarking Maize….



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  - So many lost opportunities of genetic progress for the farmers
  - So little knowledge about local availability: Genotype and further genotype !!!
  - No comprehensive breeding strategy if no optimal use of Genetic Diversity

- **Important players hosting Genetic Diversity**:
  - Côte d'Ivoire (CNRA)
  - French Guyana (Cirad)
  - Nestlé CCC
  - All countries located in the natural area of dispersion

- **Crucial to be able to share / enrich Genetic Resources** :
  - International forum with Internationally recognized Pilot in the plane / Coordinator
  - Fair agreement and acknowledgement those who preserved Genetic Ressources
  - International norms / Phytosanitary issues
  - REACTIVATE surveys: First Priority = Angola, Gabon, RDC

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Thanks for your attention

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