



Systems of Genetic Resources Exchange in Côte D'Ivoire and its Evolution: Case Study of Food Crops Such as Yam, Cassava, Rice and Plantain

**Koffi Kouablan Edmond¹, Yao Saraka Didier Martial^{2*}, Kouakou Amani Michel³,
N'Zue Boni³, Kobenan Kouman⁴, Traore Siaka⁴, Anguete Kouamé⁵
and Diarrassouba Nafan²**

¹Centre National de Recherche Agronomique (CNRA)/ Laboratoire Central de Biotechnologies (LCB),
Km17 Route Dabou, 01 BP 1740 Abidjan 01, Côte d'Ivoire.

²UFR Sciences Biologiques, Département de Biochimie-Génétique, Unité Pédagogique et de
Recherche (UPR) de Génétique, Université Peleforo GON Coulibaly, BP 1328 Korhogo,
Côte d'Ivoire.

³CNRA/Station de recherche sur les cultures vivrières; 01 BP 633 Bouaké 01, Côte d'Ivoire.

⁴CNRA/Station de Recherche de Bimbresso 01 BP 1536 Abidjan 01, Côte d'Ivoire.

⁵CNRA/Station de Recherche de Man, BP 440 Man, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Authors KKE, YSDM, KAM, ZBN, KK, TS and AK designed the study, achieved the investigations and fitted the data. Authors KKE YSDM and ND valued the experimental approach protocol and results interpretations. Authors KKE and YSDM performed the data analysis, wrote the first draft of the manuscript and managed the literature and checked the submitted manuscript for the required improvements. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Plant Genetic Resources for Food and Agriculture (PGRFA) flow in research and development area inside and outside many countries are not indexed or listed and are insufficiently documented. In Côte d'Ivoire, when implementing the Multilateral System (MLS) project, a survey

*Corresponding author: E-mail: didierys@yahoo.fr;

was realized with different actors as well at national as international levels to collect data dealing with exchanges flow characteristics of main food crops as yam, cassava, rice and plantain. The objectives of the current study are i) to know about internal and external exchange flow of genetic resources of yam, cassava, rice and plantain in Côte d'Ivoire, ii) to assess Côte d'Ivoire dependence regarding external PGRFA, iii) to identify international research agreements or research network facilitating Plant Genetic Resources (PGR) in Côte d'Ivoire and iv) to determine constraints or opportunities related to access to external PGR in the future.

Study Design: A questionnaire was submitted to actors managing main consumed food crops in Côte d'Ivoire such as yam, cassava, rice and plantain.

Place and Duration of Study: Study was conducted in 2019 and sampled data on period starting from 2005 to 2014 about the flow of genetic resources of yam, cassava, rice and plantain inside and outside Côte d'Ivoire located in Western Africa were studied.

Methodology: This comprised the collection of data using a questionnaire related to characteristics of PGRFA flow inside and outside Côte d'Ivoire, within institutions in charge of PGRFA. A survey was conducted with national and international actors involved in yam, cassava, rice and plantain genetic resources. Moreover, surveys on PGRFA flow data were supplemented by reports from research programs dedicated to these food crops.

Results: Results revealed that genetic resources of yam, cassava, rice and plantain are exchanged at variable levels within different actors. Contrary to plantain, a growth of vegetal material exchange within actors was observed at national level in yam, cassava and rice. PGRFA exchange flow at international level are positively unbalanced in favor of importation from *Groupe Consultatif pour la Recherche Agricole Internationale* (CGIAR) creating by this way a relatively marked dependence excepted to yam where ongoing varietal breeding relies on local genetic resources. Very few or no data was given back to national research and development institutions and farmers from Côte d'Ivoire on national PGRFA sent outside for breeding purposes. In the same line, neither any law nor regulations were set up at national level to ensure traceability of plant material exchanges according to international agreements and conventions.

Conclusion: The consequence of this inventory of fixtures about systems of genetic resources exchange and evolution in Côte d'Ivoire is the lack of regulatory mechanisms allowing populations owning traditional knowledge take profit of an access and a fair sharing of advantages arising from the use of PGRFA as yam, cassava, rice and plantain.

Keywords: International treaty of plant genetic resources for food and agriculture; multilateral system; genetic resources flow; food crops; Côte d'Ivoire.

ABBREVIATIONS

AIPO	:	<i>African Intellectual Property Organization</i>
AfricaRice	:	<i>Rice research institute in Africa</i>
ANADER	:	<i>Agence Nationale d'Appui au Développement Rurale</i>
BTF	:	<i>Breeding Task Force</i>
CARBAP	:	<i>Banana and Plantain Research Center</i>
CBD	:	<i>Convention on Biological Diversity</i>
CGIAR	:	<i>Groupe Consultatif pour la Recherche Agricole Internationale</i>
CNRA	:	<i>Centre National de Recherche Agronomique</i>
CSRS	:	<i>Swiss Center for Scientific Research</i>
INIBAP	:	<i>International Institute for Banana and Plantain</i>
ITPGRFA	:	<i>International Treaty of Plant Genetic Resources for Food and Agriculture</i>
IITA	:	<i>Institut International d'Agriculture Tropicale</i>
IPPC	:	<i>International Plant Protection Convention</i>
IRRI	:	<i>International Rice Research Institute</i>
MLS	:	<i>Multilateral System</i>
MTA	:	<i>Material Transfer Agreement</i>
PGR	:	<i>Plant Genetic Resources</i>
PGRFA	:	<i>Plant Genetic Resources for Food and Agriculture</i>
WAAPP	:	<i>West Africa Agriculture Productivity Project</i>
WTO	:	<i>World Trade Organization</i>

1. INTRODUCTION

Genetic resources refer to biologic diversity of microbial, animal and plant species [1]. The International Treaty of Plant Genetic Resources for Food and Agriculture (ITPGRFA) defines Plant Genetic Resources for Food and Agriculture (PGRFA) as being genetic material from plants and having an effective or potential value for food and agriculture [2-3]. In Côte d'Ivoire, the main food crops, considering production and consumption levels together, are composed in descending order of plantain, rice, cassava and yam.

In Côte d'Ivoire, many species of yam or *Dioscorea spp.* (*Dioscoreaceae*) are clustered in two groups: precocious yams and late ones. These two kinds of yam are cultivated on 830,000 ha with a total annual yield estimated to be 6.9 million tons in 2013 [4-5]. In terms of yield and consumption, yam is the first food crop in Côte d'Ivoire. Annual consumption per capita ranged from 105 to 120 kg in last decade [4].

Cassava (*Manihot esculenta* Crantz) from *Euphorbiaceae* family is the second food crop in Côte d'Ivoire, after yam, with a yield estimated to be 4.42 million tons in 2014 [4-5]. Cassava, used at the same time for human food and animal feed, but also in industry (textile, paper, etc.), constitute a food and cash crop [4-8]. Derivatives products from cassava are so many ("attiéké", "foutou", "toh", flour, starch, "gari", etc.) and traded locally and sub-regionwide.

Cropping of rice (*Oriza sp.*), a cereal from *Gramineae* family is the third food crop after yam and cassava, in Côte d'Ivoire [4]. Rice cultivation is mainly dominated at more than 80% by land rice that occupies 700,000 ha. With a yield estimated to be 650,000 tons of husked rice, national production in rice is far below needs that are 1.3 million tons per year, consumption per person being 60 kg per year [4].

Plantain, in terms of consumption, is the third food crop in Côte d'Ivoire after yam and cassava but its annual production is estimated to be 1.6 million tons [4-5]. This production volume allows ranking Côte d'Ivoire at the third place of producers in West Africa, after Nigeria and Ghana. Globally, plantain is produced in extensive systems based on rudimentary agricultural-tools, weak productive landraces, susceptible to nematodes, black weevil and black leaf spots diseases [9]. Basically, genetic

diversity in plantain increased in Côte d'Ivoire since last decade. An enrichment of germplasm was registered with introduction of improved varieties by Centre National de Recherche Agronomique or CNRA [9-10] and those from International Institute for Banana and Plantain (INIBAP).

In Côte d'Ivoire, since research institutes and higher schools creation till their functioning to now, genetic resources of yam, cassava, plantain and rice are exchanged at the national and international levels, on the basis of international agreements and conventions ratified by many developing countries. All these exchange that deals with an important genetic resources flow for creating and selecting improved varieties in order to satisfy farmers needs are not indexed or listed and documented. Such situation leads to a lack of data not allowing receiver and donor countries of these resources to take profit as recommended by Multilateral System, through a fair sharing of benefits arising from the use of these PGRFA. The goals of the current study are i) to know about internal and external exchange flow of genetic resources of yam, cassava, rice and plantain in Côte d'Ivoire, ii) to assess Côte d'Ivoire dependence regarding external PGRFA, iii) to number or indentify international research agreements or research network facilitating Plant Genetic Resources (PGR) in Côte d'Ivoire and iv) to determine constraints or opportunities related to access to external PGR in the future.

2. METHODOLOGICAL APPROACH OF THE STUDY

The data were gathered using a questionnaire related to characteristics of PGRFA flow within institutions in charge of PGRFA inside and outside Côte d'Ivoire. A survey was conducted in 2019 with national and international actors involved in yam, cassava, rice and plantain genetic resources. Added to questioned actors, survey's questionnaire was fill out from documentary sources developed within Root and Tuber Crops Programme (Yam and cassava), Plantain/Banana/Pineapple (Plantain) and Rice of the *Centre National de Recherche Agronomique* (CNRA) in Côte d'Ivoire. Management and following up of entering and outgoing flow of GR studied were considered for the period starting from 2005 to 2014.

From four samples of survey records according to crops (yam, cassava, rice and plantain), analytical study of quantitative and qualitative

data recorded began by a typology of different actors involved in these food crops management. Hence, actors involved in Genetic Resources (GR) of yam, cassava, rice and plantain exchanges identified at national and international level were split in five groups: research, development, private sector, farmers and traders Fig. 1. The main identified actors were listed per crop at national and international scales. Four flow intensities (unknown, weak, moderate and intensive) of plant genetic resource were used to characterize the exchanges within formerly identified actors. Also, each flow intensity was transformed in quantitative data, 0 for unknown, 1 for weak, 2 for moderate and 3 for intensive to carry out statistical analyzes. With SPSS version 20 (IBM corp., USA) software, the flow intensity means were estimated to compare genetic resources flow for four studied food crops at national and international scales from ANOVA and Student tests.

In Côte d'Ivoire, internal exchanges flow of GR of yam, cassava, rice and plantain occurs at variable intensity degrees between research, development, private sector, farmers and traders. Indeed, in yam at local level, exchanges flow is intensive between farmers and remains moderate between research and farmers. However, this exchanges flow is at a low level in one hand, between research and extension, private sector and development and in the other hand between private sector and development, farmers and development. This low exchanges flow is also observed between development and farmers and between farmers and traders. At external scale, in yam, exchanges flow is moderate between research institutions, between farmers, between traders, between development and farmers and between farmers and traders.

Dealing with cassava, at internal level, exchanges flow of GR is intensive between research and extension, between research and farmers, between extension and farmers and between farmers. Exchange's flow is a moderate level when it concerns research institutions between them, from extension agencies to development, from farmers to traders. Exchange's flow is rare between research and private sector, research and development, between private sector and farmers and also between farmers and traders. Dealing with relations between Côte d'Ivoire and outside, exchanges flow of GR of cassava between research institutions is poor as they are between research and development.

3. RESULTS

3.1 Flow of Genetic Resources of Yam, Cassava, Rice and Plantain inside and outside Côte d'Ivoire

3.1.1 PGRFA exchanges flow characteristics

An exchange flow of Genetic Resources of yam, cassava, rice and plantain exists between actors at national level and at international scale between the same actors Fig. 1.

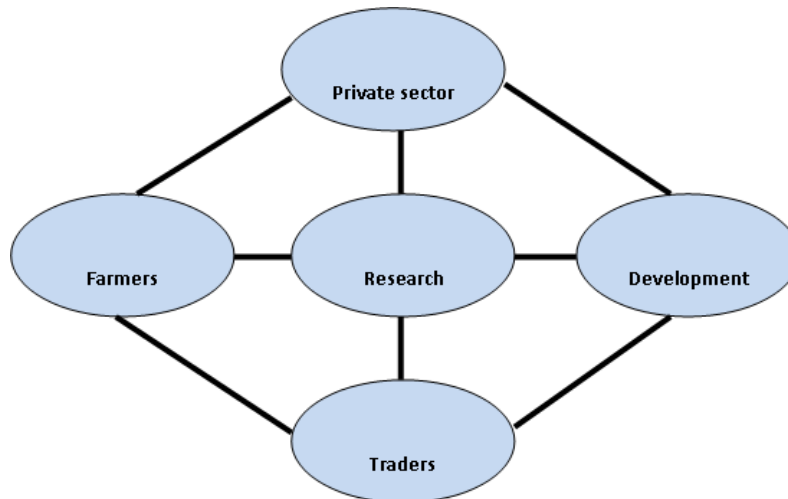


Fig. 1. Groups of national and international actors involved in genetic resources of yam, cassava, rice and plantain flow exchanges

Rice genes flows between research institutions are very intensive within Côte d'Ivoire. They are carried out mainly between CNRA, universities, higher schools in agricultural field. Two entities that are private sector and research do not share a common platform for rice GR exchange.

Plantain GR exchange level, nationwide, between research and extension structures and farmers are moderate as is the case between private sector and farmers and between the last ones. It is weak between research and the others actors and unknown between research, development institutions and farmers. At the opposite, it is intensive between farmers and traders. Plantain GR exchange level between actors at international level is basically weak between the research and other actors (farmers, private sector, traders and development) and unknown between this last group of actors themselves. However, the level of exchanges is moderate between traders.

To consider all actors, the intensities of genetic resources exchange of yam, cassava, rice and plantain were similar ($F=1,353$; $p = 0,243$) at national level. But at the international scale the exchange intensities between all actors were high for yam than those scored for cassava, rice and plantain where exchange levels varying from 0 (unknown data) to 1 (weak intensity) Fig. 2.

To consider studied food crops globally, the intensities of genetic resources exchange between main actors (research, development, private sector, farmers and traders) were different significantly at nationwide ($F=4.187$; $p < 0.001$) and international scale ($F=2,045$; $p = 0.049$). At nationwide scale, the exchange intensities between farmers, between research and farmers and between researches were high and at international scale the high intensities of genetic resource exchanges were scored between researches Fig. 3.

3.1.2 PGRFA exchange flow evolution

PGRFA exchange flow in yam at nationwide registers an increase between research institutions, between research and development and between development institutions and farmers. But, exchanges between research and private sector and between private sector and farmers appears constant from 2005 to 2014. But, a decrease of exchanges between private sector and development institutions was noticed. Relationship levels between outside and Côte

d'Ivoire, exchanges between research institutions, between research and the other components (private sector, farmers, development) were constant.

Within the country, exchanges flow in cassava raised from 2005 to 2014 between research institutions, between research and development institutions and also between farmers and the other components (research and development institutions) were in the same line between farmers. In the same period, between Côte d'Ivoire and outside, cassava GR exchanges between research institutions, as research and development institutions was constant.

Gene flow in rice within the country faced a substantial increase from 2010 to 2014, in consideration of new breeding methods implemented.

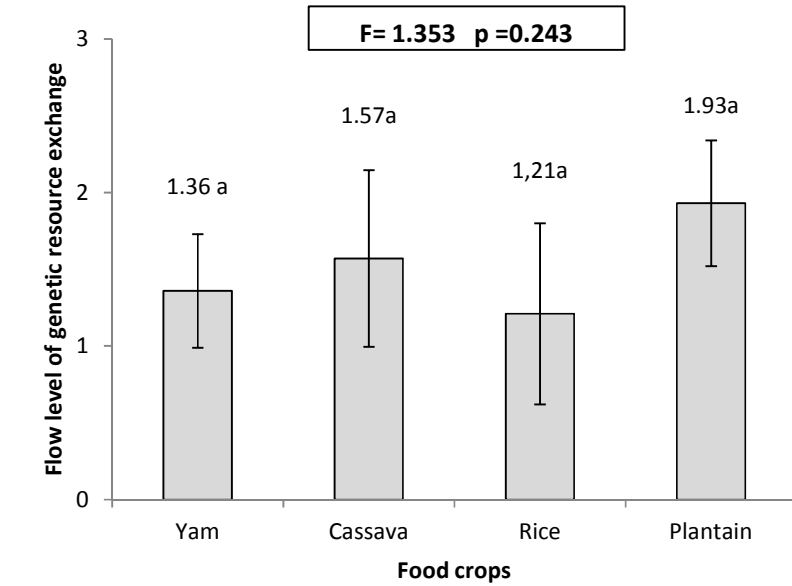
Basically in plantain, at nationwide as international level, GR exchange flow increased between actors. Two hybrids to black leaf spot disease (PITA 3 and FHIA 21) are in course of extension based on WAAPP (West Africa Agriculture Productivity Project) in many regions in the country. More than 200 000 *in vivo* plantlets of these hybrids including those from traditional varieties as *Corne 1* and *Orishele* were also distributed in different areas of the country. *In vitro* plantlets from *Big Ebanga* variety were distributed through WAAPP to nursery farmers associations for mass multiplication as planting material.

3.1.3 Introduction and genetic resources management in yam, cassava, rice and plantain

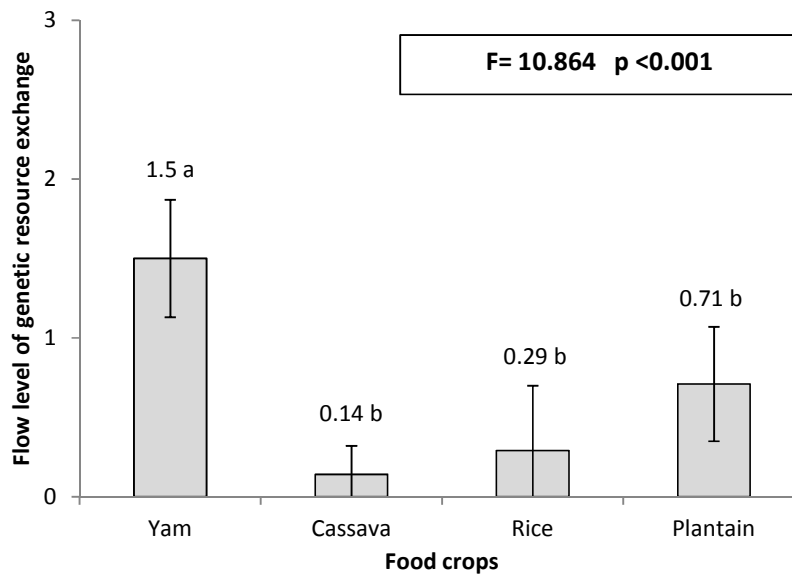
Introductions of yam in 2007 occurred with 100 improved varieties from International Institute Tropical Agriculture (IITA) as cuttings estimated to 3 tons. These introductions enriched yam collection at CNRA composed of *Dioscorea praehensilis* (2), *D. mangelotiana* (11), *D. munitiflora* (1), *D. alata* (164), *D. cayenensis* (45), *D. rotundata* (191), *D. abyssinica* (3), *D. bulbifera* (5), *D. dumetorum* (3), *D. esculenta* (3), *D. shimperiana* (1), *D. togoensis* (7) accessions. Moreover, collection of yam at CNRA include 99 interspecific hybrids resulting by crossing *D. rotundata* var. krengele x *D. praehensilis* and intraspecific hydrides within *D. alata* x *D. alata* (42), that gives a total number of 577 accessions. However, it was observed a loss of accession on farm during conservation. To face such loss, a collecting genetic resources

prospection of yam was realized in 2011 and founded by WAAPP project. Now, yam collection includes 519 *in vivo* accessions conserved on

farm at Bouaké and 201 *in vitro* accessions conserved at Laboratoire Central de Biotechnologies in CNRA at Adiopodoumé.



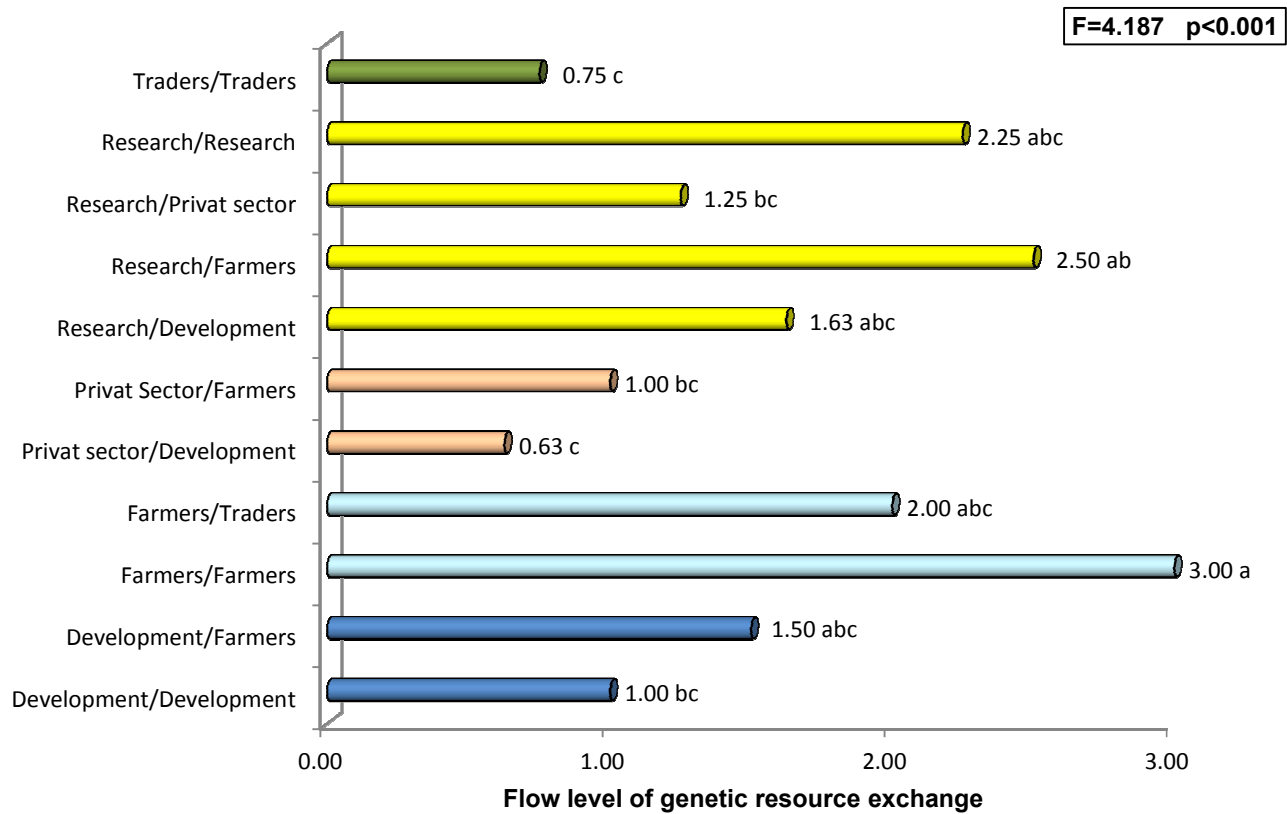
a. National exchange



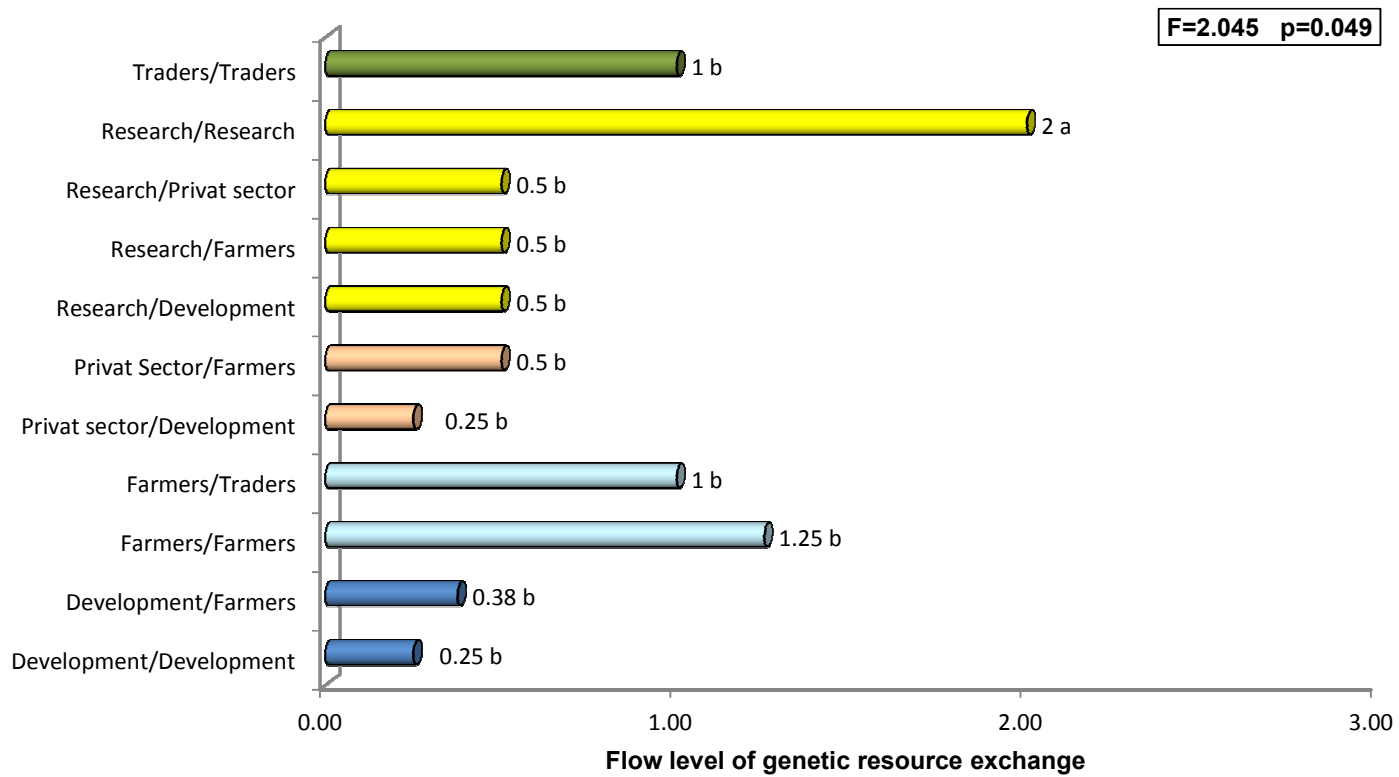
b. international exchange

Values with the same letters on the histograms are statistically identical.

Fig. 2. Intensity of exchange flow of genetic resources of yam, cassava, rice and plantain (a) inside and (b) outside Côte d'Ivoire



a. National exchange



b. International exchange
 Values with the same letters on the histograms are statistically identical.

Fig. 3. Flow intensity between actors involved in genetic resources of yam, cassava, rice and plantain exchange at (a) national and (b) international scales

A total of 80 varieties of improved cassava varieties were introduced at CNRA from IITA as cuttings. These plant materials were assessed and conserved on research stations since their introduction. Eleven productive orange flesh varieties were chosen as parents and crossed with local varieties for creating polyvalent and provitamins A-rich varieties. Three other varieties were selected for demonstration tests on farmer's field based on yield, dry matter content and tolerance to root rot disease. Variety Bocou 1 in extension process since 2008 is largely spread. It is productive, multiuse and with a high multiplication rate. All in all, about fifteen (15) improved varieties were transferred at farmers' level. At research scale, yield range from 28 to 34 ha with a dry matter content comprised between 33 % to 30 t/ha Table 1. Taken all round, at farmers' scale, yields varied from 20 to 30 tons per hectare.

Promising rice lines received from 2008 to 2016 varied from year to year Table 2. All in all, 1056 lines originating from *AfricaRice* were received over this period as sample seeds of 3.2 kg to 15.57 kg with a total weight of 56 kg Table 2.

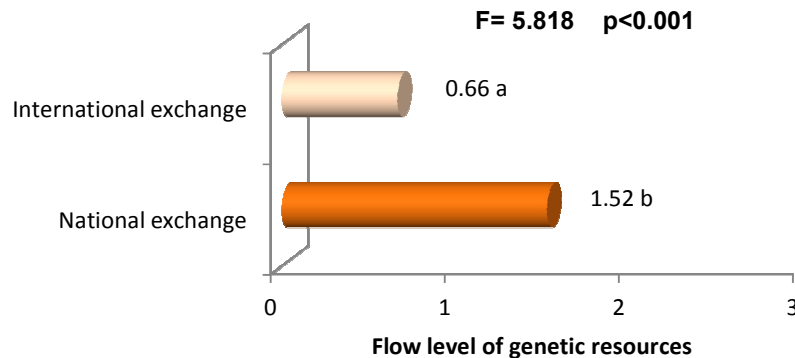
In field genetic improvement, international research centers released high yielding and tolerant to pests tetraploids hybrids in plantain. Tested material, being extended in several areas of the country was introduced as *in vitro* plantlets (5 to 10 per genotype) Table 3. Irrespective of these improved varieties introduced by international research institutions, 43 traditional varieties were also introduced as planting material in 2006 and 42 others collected locally

through prospection were added to resources in collection at CNRA.

3.1.4 Exportation and management of PGRFA from Côte d'Ivoire

In 2011, 99 yam landraces as cuttings were exported to IITA by CNRA. Until 2016, yam seeds and cuttings were exported by CNRA to IITA and NCRI respectively. In 2005, 16 cassava varieties including 10 landraces and 6 improved varieties were also exported to IITA. Since exportation of these materials no information dealing with them was received back from IITA. In rice, on the fringe of the promising lines tested, other genetic materials collected at farmer's level were exchanged from Côte d'Ivoire to international institutions. These seed of the rice are shared to institutions as *AfricaRice* for characterization. Thus, 35 rice lines were exported to *AfricaRice* in 2012 and 2015. In 2016, *AfricaRice* was received from Côte d'Ivoire, 7.5 kg of two rice lines which are ARICA 14 and ARICA 15. In plantain, 720 *vivo* seedlings of PITA3 and FHIA21 varieties were sent to Burkina Faso, Benin and Togo for multi-trial tests.

The levels of flow at national scale were more than those realized at international scale ($F=5,818$; $p < 0,001$). While international flow varying between 0 (unknown data) and 1 (weak intensity), national exchanges were more than 1 and closed to 2 (moderate intensity) Fig. 4. Nevertheless, at international level, exchange rates of GR were high (57%) between traders Fig. 5.



Values with the same letters on the histograms are statistically identical.

Fig. 4. Intensities of national and international exchange of genetic resources of yam, cassava, rice and plantain

Table 1. Evaluation in 2012 of introduced varieties of cassava from IITA, their improvement at CNRA and their release in farms in Côte d'Ivoire

Released varieties	Origin	Production cycle (month)	Cultivation area ⁽¹⁾	Tolerance to viruses	Tolerance to mites	Tolerance to cochineals	MYRS (t/ha)	PDM (%)
Bocou1	CNRA	12 to 20	Extended	Good	Weak to moderate	Weak to moderate	34	39
Bocou2	IITA	11 to 18	Centre, South, Eastern-South, West	Good	Weak to moderate	Weak to moderate	32	38
Bocou3	CNRA	11 to 18	Centre, Eastern-South	Good	Bonne	Good	32	37
TMS4(2)1425	IITA	11 to 18	Extended	Good	Weak to moderate	Moderate	30	36
IM93	CNRA	12 to 20	Centre, South, West, Western-Centre	Good	Moderate	Moderate	28	38
IM89	CNRA	12 to 20	Centre, South, West, Western-Centre, East	Good	Moderate	Moderate	28	40
IM84	CNRA	11 to 18	Extended	Weak to moderate	Good	Good	30	35
TMS30572	IITA	12 to 18	Extended	Good	Weak to moderate	Weak to moderate	30	35
TMS30001	IITA	11 to 20	Western-South	Good	-	-	30	33
TMS30555P3	IITA	11 to 18	Western-South	Good	-	-	30	35
Ka13	Kenya	11 to 18	Western-South	Good	-	-	30	39
85/637	CNRA	11 to 18	South	Moderate	-	-	30	36
TMS30395	IITA	11 to 18	South, Western-South	Good	-	-	33	35
79(01)	CNRA	11 to 18	South, Western-South, Western-North	Moderate	-	-	30	35
88/263	CNRA	11 to 18	Centre, West, Western-South	Moderate	-	-	30	35
Yavo	IITA (CSRS)	11 to 18	Extended	Good			32	39

MYRS : mean yield in Research Station; PDM : Percentage of Dry Matter ;⁽¹⁾ Areas where the variety is cultivated (non exhaustive data); CNRA: Centre National de Recherche Agronomique (National Center for Agronomic Research); IITA: International Institute for Tropical Agriculture; CSRS : Centre Suisse de Recherche Scientifique (Swiss Center for Scientific Research)

Table 2. Evaluation from 2008 to 2016 of promising rice lines received from *AfricaRice* and their quantities

Year	Number of line	Quantity (kg)
2016	172	15.57
2015	102	9.18
2014	134	5.36
2013	169	6.73
2012	159	6.36
2011	120	4.8
2010	40	1.6
2009	80	3.2
2008	80	3.2
Total	1056	56

Table 3. Evaluation of improved hybrids of plantain received, tested and released in Côte d'Ivoire

Genotype	Origin	Year of introduction	Observations
FHIA 01	FHIA	1999	Lost
FHIA 17	FHIA	1999	In collection
FHIA 21	FHIA	2002	On release
FHIA 23	FHIA	1999	In collection
FHIA 25	FHIA	2002	In collection
SH 3640	FHIA	1999	In collection
TMBX 548-4 (BITA 1)	IITA	1999	Lost
TMBX 1378 (BITA 2)	IITA	1999	Lost
TMPX 4479 -1(PITA 17)	IITA	1999	Lost
TMPX 548 -4 (PITA 1)	IITA	1999	Lost
TMPX 2796 -5 (PITA 5)	IITA	1999	Lost
TMPX 5511-2 (PITA 3)	IITA	1999	On release
TMPX 4698-1 (PITA 6)	IITA	1999	Lost
TMPX 7002 -1 (PITA 8)	IITA	1999	Lost
TMPX 1152-2	IITA	1999	Lost
TMBX 5295-1 (BITA 3)	IITA	2002	In collection
TMBX 15108-6 (PITA 16)	IITA	1999	Lost
CRBP 14-1	CARBAP	1999	In collection
CRBP 39-1	CARBAP	1999	In collection
CRBP 85-1	CARBAP	1999	In collection
CRBP 100-1	CARBAP	1999	In collection

3.1.5 Climate change and genetic improvement of yam, cassava, rice and plantain

Contrary to yam, cassava and plantain varieties, only rice genetic resources have been assessed for climate change. The exchange of rice genetic materials between Côte d'Ivoire and international agricultural research institutions such as the International Rice Research Institute (IRRI), IITA and *AfricaRice* are favored by the fact that Côte d'Ivoire is a member of Breeding Task Force (BTF) coordinated by *AfricaRice*. Indeed, in collaboration with *AfricaRice*, screening trials of pluvial rice lines are conducted since 2011 to identify drought-tolerant genotypes. However,

genetic resources of yam, cassava and plantain in conservation process are an important reservoir of varieties potentially adapted to new climatic conditions. For example, the cases of no tested variety TDa01/00113 for yam dealt in farmers since 2015 and no tested varieties IM93 and CM52 (or Bocou1) for cassava dealt in rural environment since 1998 and 2008 respectively.

3.2 Dependence of Côte d'Ivoire on External PGRFA

There is an external dependence on PGRFA for all the crops studied. However, this dependence is to varying degrees, depending on the crop.

Indeed, dependence of yam RGs on outside various institutions is moderate. The National Agency for Rural Development Support (ANADER in French) is the only development structure approved by the State, which allows the dissemination of yam RGs to farmers. It is entirely dependent on research structures such as CNRA, Swiss Center for Scientific Research (CSRS in French) and some public universities. Use of external PGRFA allows enrichment of varietal range of producers, who are the first direct actors of the yam cultivation. Despite this, CNRA's dependence on yam external resources in its selection and improvement scheme is decreasing. In the recent past, however, CNRA's Root and Tuber Plants Program used accessions seeds (tubers) from outside to select and create varieties. But, because of cross-breeding difficulties, plant material exchanges in the form of tubers were good means of accelerating varietal selection, even if it is not totally dependent on it. In 2012, varieties CivCda

053 and CivCdr 015 were developed and released at medium-scale in rural environment. Likewise varieties TDr01/00406, TDr99/02552, TDa01/00113, TDAa01/00090, TDa01/00018 TDr01/00406, TDr99/02552, TDa01/00113, TDAa01/00090 and TDa01/00018 created in 2015 from exotic materials of yam were diffused in rural environment.

In cassava, dependence on external institutions, in consideration of plant material for research purposes is constant and moderate as many varieties were developed based on local resources. However, TMS4 (2) 1425, TMS30572, 188 / 00158 varieties and 20 others were involved in opened and controlled crosses with local varieties followed by several years of field selection. For example, variety IM93 was disseminated to population at relatively low scale since 1998, that is not the case for CM52 (also known as Bocou1), which was widely distributed on a large scale since 2008.

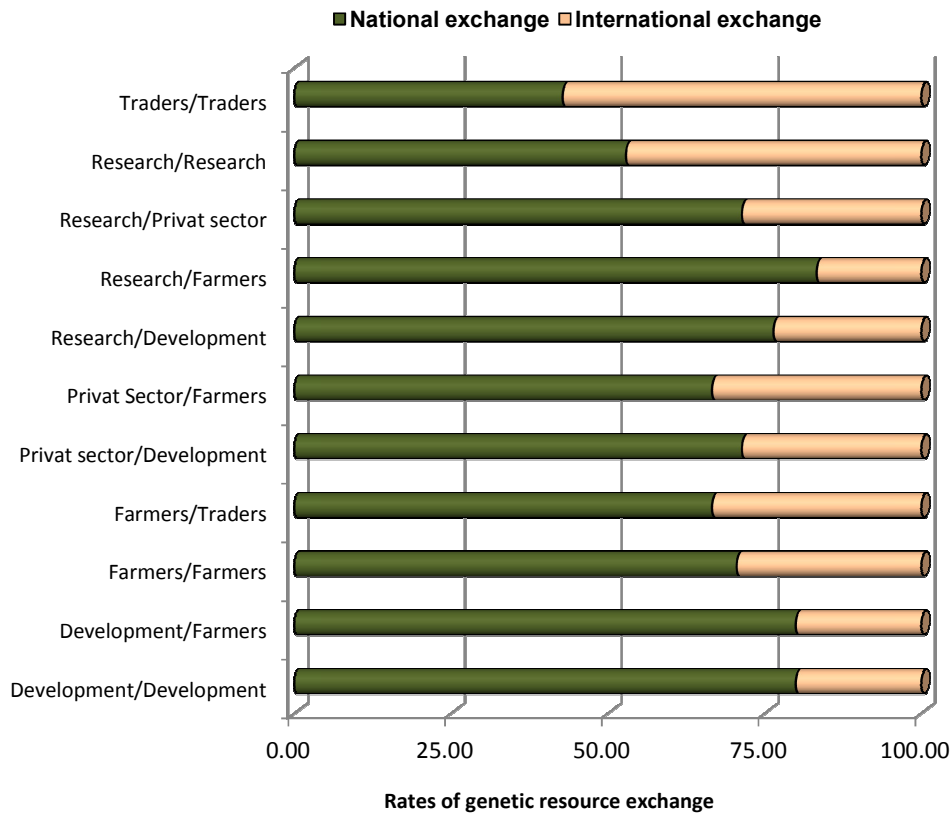


Fig. 5. Rates of national and international exchanges between actors involved in genetic resources flow of yam, cassava, rice and plantain

For rice, observed dependence was increasing and was used mainly for the evaluation and selection of new lines. Since 2011, Côte d'Ivoire participates every year in assessing promising rice lines for drought tolerance in pluvial ecology and for ferrous toxicity tolerance for lines tested in irrigated lowland ecology. Thus, CNRA rice program receives about 150 promising lines to be tested in both ecologies. This abiotic stress is becoming increasingly widespread in dregs of Côte d'Ivoire and its effects are accentuated by rainfall scarcity. Indeed, abundance of rainfall leaches excess iron in irrigated lowland and thus attenuates its effect on cultivated varieties. Thus, the less severe rainfall will be the effect of ferrous toxicity, and the greater the crop losses due to this stress.

In relation to plantain, regarding outside institutions, dependence consisted in receiving improved varieties that served as basis for the creation of new varieties and/or direct dissemination into farming environment after agronomic and technological assessments. This is the case for the FHIA 21 and PITA 3 varieties that were dealt with on an average scale, unlike Orishele variety, which was disseminated on a large scale from 2008 to 2012.

3.3 International Agreements on PGRFA Trade in Côte d'Ivoire

3.3.1 Institutional factors in international trade in PGRFA

In general, policies do not take sufficient regulatory texts (laws, decrees, orders) relevant to development of PGRFA at national level. This results in many shortcomings in the implementation of international exchanges in plant genetic resources (PGR). Nevertheless, exchanges of plant material between countries or research centers are carried out within a legal framework often embodied in a Material Transfer Agreement (MTA).

At the international level, Côte d'Ivoire is a signatory to most agreements and conventions related to environment protection in general and to plant species constituting biodiversity, in particular. There are two major international conventions governing the management of plant genetic resources. This is the Convention on Biological Diversity (CBD) which was signed in Rio in June 1992 and which registered the accession of Côte d'Ivoire on 24 November 1994; The International Treaty on Plant Genetic

Resources for Food and Agriculture (ITPGRFA) signed in 2001 and ratified in 2003 and the International Plant Protection Convention (IPPC) of 9 August 2000. To these conventions, can be added those related to humid areas (RAMSAR), to International Trade in Endangered Species of Wild Fauna and Flora (CITES), to fight against desertification, to Cartagena Protocol on Biosafety, to Agreement establishing The World Trade Organization (WTO), to the Bangui Agreement establishing an African Intellectual Property Organization (AIPO).

Apart from the phytosanitary protection laws that are strictly observed when importing and exporting plant material, there are no laws at the national level applied to plant genetic resources, thus creating an administrative environment favoring the informal exchange of material Plant, nationally and internationally. Thus, conservation of traditional varieties is carried out freely by farmers and no governmental incentive policy is set up for its promotion. Improved seeds are usually produced by research centers or national agricultural development companies and freely sold without special legislation.

Research structures that achieved many results in the conservation of cultivated species are co-opted to be the main implementing agencies.

3.3.2 Introduction and management of PGRFA included yam, cassava, rice and plantain genetic resources in Côte d'Ivoire

Membership of Côte d'Ivoire to the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) facilitates germplasm exchanges. As the general legal framework is created, national structures such as CNRA can share genetic resources with other structures; leading to an expansion of the genetic base of the local gene bank. Genetic improvement of agronomic and technological interest traits of these genetic resources could then be facilitated.

RPG exchanges take place within a legal framework based on international agreements or research networks. Among networks facilitating exchanges, is the Consultative Group for International Agricultural Research (CGIAR). IITA, the African Banana and Plantain Research Center (CARBAP in French) and AfricaRice are regional research institutes funded by a number of countries through the CGIAR. Côte d'Ivoire has imported more than 100 improved varieties

of cassava from IITA since the 1980s. In return, IITA has collected 16 varieties of cassava from Côte d'Ivoire, including 6 local varieties and 10 improved varieties. These exchanges took place on the basis of the TMA. Like cassava, genetic resources were exchanged between AfricaRice, CARBAP and CNRA for rice and plantain.

3.4 Constraints / Opportunities for Access to External PGRFA Included Yam, Cassava, Rice and Plantain Genetic Resources

Opportunities from external RPG access in the future will enrich the collections, broaden the genetic base, increase genetic gain and production, build a gene bank of diverse origins and introduce genotypes of agronomic and economic interests. These external genetic resources can be used for varietal breeding and genetic improvement. The constraints can be summarized by the introduction of new bio-aggressors accidentally and varieties not adapted to socio-economic conditions; hence the creation of quarantine centers and services for research institutes to monitor the introduction of PGRFA.

4. DISCUSSION

Description of genetic resources flow characteristics showed that, beyond to the relatively large exchange of yam, cassava, rice and plantain plant material, weaknesses were identified between actors both nationally and internationally. These weaknesses lie at two levels: the first being amplitude/frequency of exchanges and the second relations between actors. While the level of exchanges at national level was low between research and the private sector, research and NGOs, between the private sector and farmers, and between farmers and traders, in terms of external relations with Côte d'Ivoire, exchanges of genetic resources between research institutes were rare, as well as between research and NGOs. The weak level of genetic material flow between international actors could be explained by the lack of data about genetic resources of yam, cassava, rice and plantain. From the point of view of relations, the lack of information on actors categories did not allow evaluating the level of plant material exchanges in yam and cassava as well as in plantain, unlike of rice where exchange level of plant material was described in all actors. Contrary, level of trade relations was intensive

between farmers and traders, certainly for commercial reasons.

Description of plant material flow characteristics allow observing that weaknesses exist both as well in terms of the exchange levels as relations between different actors with regard to main food crops in Côte d'Ivoire. These weaknesses show that plant material exchanges do not occur as it should do, and this was to the detriment of our resources, as evidenced with regard to outside dependence. Indeed, many resources were introduced into our collections from the Consultative Group for International Agricultural Research (CGIAR) centers for evaluation or cross-breeding purposes in order to create new varieties. In contrast, very few resources were provided to these centers. More seriously, no reliable information dealing with subsequent uses of these resources is available (case of the 10 varieties of cassava sent to IITA in 2005), although some improved varieties from local resources transmitted to some CGIAR centers are being released, like Nerica 1 and 2.

Similarly, previous crosses between about 20 improved cassava varieties introduced from IITA and local varieties led to creating several varieties, from which some were transferred to farmers through varietal tests [11-14]. Dealing with plantain, bilateral exchanges between CNRA and the providing institutions (IITA and CARBAP) made it possible to test and disseminate improved exotic hybrids in Côte d'Ivoire [15-16]. Yam, cassava and plantain varieties have not yet been studied with regard to climate change in Côte d'Ivoire, despite the disturbance of cultural calendars noticed.

All of these weaknesses listed above give evidence of the relevance of the study on gene flow on major food crops. Once evidenced, these weaknesses should be taken into account in order to find solutions to allow a good flow of plant material between the various national and international actors. In addition, regulatory environment will have to be strengthened, in terms of laws adoption, decrees and implementing decrees to improve at institutional and administrative levels the exchange of plant material, as reported by [17]. Taking such an option, request to face the lack of national mechanism for genetic resources in general and for plant genetic resources, in particular, to put an end to or to some extent diminish significantly the informal exchange of plant material, both nationally and internationally. Given that it was to

annihilate such practices that the ITPGRFA with its multilateral system was wished and desired by the signatory countries including Côte d'Ivoire. Provision should therefore be made for the effective and efficient implementation of these international agreements and conventions at national level.

5. CONCLUSION

Through the Multilateral System, genetic exchange flows contribute to enriching the national collection and facilitating genetic improvement of agronomic and technological traits of interest. This indicated that the strong involvement of the State of Côte d'Ivoire in the field of biological diversity by financially, humanely and technically supporting research, development and farmers had been of great importance. The Ivorian State must also adopt relevant laws on the conservation and sustainable use of Plant Genetic Resources for Food and Agriculture (PGRFA) and establish structures for the effective implementation of these Conventions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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