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Challenges facing the cotton sector worldwide and in Africa

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Abstract

To prepare the roadmap for its ten-year research on the cotton sector, CIRAD worked with a number of stakeholders to identify the main challenges facing the sector in the coming years, both globally and in Africa in particular. This document presents the 35 challenges identified, grouped into 7 macro-challenges. Several of these challenges are global in scope, and international collaboration is needed to address them.

Keywords: cotton sector, challenges, impacts, climate change, profitability, well-being, research and development, image.

Introduction

CIRAD (https://www.cirad.fr/en) is the French agricultural research and international cooperation organization for the sustainable development of tropical and Mediterranean regions. Through the tropical agricultural sectors in which it is involved, its activities are structured by the impacts to which it wishes to contribute. In order to adapt its long-term vision and prioritize its future actions within the cotton supply chain, CIRAD prepared its “Cotton Roadmap”. It aims at setting a course for its activities in the field of cotton research over the next ten years, up to 2033.

CIRAD’s Cotton Roadmap was built on the challenges facing the cotton sector. A CIRAD think-tank identifed the challenges that the cotton sector is presently facing or will face in the near future, and to which the sector will have to respond through strategic orientations and choices. Although the challenges cover all the geographical areas and segments of this commodity chain, given CIRAD's mandate, we chosed to approach these challenges more specifically from the angle of cotton production for sustainable family farming in Africa.

A first set of challenges were identified, shared and discussed with several partners from CIRAD, including the International Cotton Advisory Committee. Finally, 35 challenges were selected and grouped into the 7 following macro-challenges (MC):

- MC 1. Reducing the environmental and health impacts of the cotton sector
- MC 2. Contributing to the mitigation of climate change and adapt to its effects
- MC 3. Improving the economic profitability of the sector
- MC 4. Contributing to the well-being of the sector's actors and their families
- MC 5. Developing the production of “identity” cottons
- MC 6: Strengthening research and development structures, actors and actions
- MC 7. Improving the image of the cotton sector among the public at large.

The 35 selected challenges are presented in this paper.

Macro-challenge 1. Reducing the environmental and health impacts of the cotton sector

At the global level, several stages and processes of the cotton industry contribute to the loss of biodiversity, soil degradation and affect water quality, and have a negative impact on the environment and human health. To reduce these negative externalities, it is necessary to limit the use of synthetic products and to resort to practices with a lower impact on the environment (agro-ecological transition, organic production).

Challenge 1. Developing novel ecofriendly and environment friendly technologies for controlling pests and diseases

The high pressure of bio-aggressors (insects, mites, cryptogamic, bacterial and viral diseases, weeds) has a significant negative impact on the level of production and sometimes leads to excessive pesticide or herbicide treatments. In some cases, they contribute to the development of resistance, with a negative impact on non-target fauna (especially auxiliary fauna) and on human health. It is therefore necessary to identify selective pesticides that pose the lowest risk for pest resurgence and have the least effect on biodiversity. This includes novel technologies such as the use of endophytes, food sprays for insect-predators, electronic sensors and AI for pest and disease diagnosis, new botanicals, effective biopesticidal strains *etc.*, for effective and ecofriendly pest management. In Western and Central Africa, in the context of a majority of conventional crops (*i.e.* non-GMO), several innovative methods are possible: trap plants, mulching, “push-pull” system, reinforcement of auxiliary fauna, biopesticides, pollarding, “landscape” approach, companion plants, without forgetting varietal resistance.

Note: organic production is a Macro-challenge in its own right (see MC 5).

Challenge 2. Implementing regenerative agricultural technologies and sustainable land management to improve or restore soil health and fertility

Degradation is significant in the former cotton-growing basins, in terms of organic matter content, structure, soil biology, *etc.*

To rejuvenate soil health and fertility, it is necessary to mobilise the processes of ecological intensification of cropping and production systems and regenerative agricultural strategies such as improved fallows, conservation tillage, recycling of crop residues, cover crops, legume rotation crops, biofertilisers, manures, composting, green manures, biochar, hydrochar, *etc*. Their implementation requires in parallel securing access to land for producers (see Challenge 22).

Challenge 3. Rationalising and optimise the water use

More than half of the world's cotton fibre production comes from irrigated crops (source ICAC, 2022). Competition between irrigation water and water for domestic use is mainly a problem in developed countries. However, fairer water pricing and the development of precision agriculture are encouraging a reasoned and more responsible approach to irrigation, aiming to reduce waste through adapted and targeted inputs. Rationalisation and optimisation of water use include approaches such as soil cover, water harvesting, watershed management, contour management and mulching to facilitate drainage, prevent flooding, protect from land degradation and the loss of soil moisture.

In Africa, with the exception of South Africa, Egypt, Sudan and Ethiopia, that irrigate all or part of their cotton areas, production comes exclusively from rainfed crops. With the increasing uncertainties due to climate change (see MC 2), rainfed crops face more rainfall hazards, which can be detrimental to the crop. In addition to innovative cultivation practices (see Challenge 6) and adapted varieties (see Challenge 7), the installation of retention basins would make it possible to control the availability of water for the cotton crop without negative impact on the environment.

Challenge 4. Reducing deforestation due to cotton cultivation

At the global level, demographic pressure and the expansion of agricultural land linked to human needs (food, energy, clothing, *etc*.), low yields, soil exhaustion and the increase in fallow periods contribute to deforestation. And in some regions, cotton cultivation is involved in this practice. Increasing yields, productivity and land use efficiency would make it possible to control the extension of the surface area and to reduce the need for deforestation. Moreover, the addition of organic matter would make it possible to reduce fallow periods.

Challenge 5. Reducing the impact of the textile industry on the environment

Cotton is the most important natural fibre in terms of volume and represents a quarter of the world's fibres; it is widely used in the textile industry. However, this industry makes extensive use of polluting products (for bleaching, dyeing, printing, finishing, etc.), which are too often discharged untreated into the environment and end up in the water table or surface water. This negative impact is partly due to cotton. A major challenge is therefore to change industrial practices, by promoting international standardisation and certification rules on the one hand, and by developing alternative methods that are less polluting on the other.

Another negative impact of the textile industry on the environment is linked to the export of second-hand textile products to developing countries, particularly in Africa. As a direct consequence of the excesses of fashion or “fast fashion” in developed countries, they end up in open-air dumps, polluting water tables, rivers and oceans.

Challenge 6. Reducing greenhouse gas emissions

Cotton production uses chemical inputs: fertilisers, pesticides, herbicides, defoliants, etc. Their manufacture, transport to production areas, application and degradation are all sources of greenhouse gas emissions. Alternatives to these chemical inputs exist and should be developed wherever possible. These include the use of improved varieties, natural inputs, innovative and sustainable farming methods, such as substituting nitrogenous fertilisers with nitrogen fixing by legume rotation crops or legume intercrops/covercrops.

Macro-challenge 2. Contributing to the mitigation of climate change and adapt to its effects

The visible and expected effects of climate change (CC) will be evidenced mainly in the form of an increase in average temperature, atmospheric CO_2 content and the number of violent events (tornadoes, heavy rainfall, pockets of drought, etc.), and greater variability in precipitations (cumulative amount, distribution, intensity). In relation to cotton cultivation, they will result in a shortening of the length of the cropable cycle and an increase in evaporative demand, as well as in the occurence of water and heat stresses. The impacts will be felt particularly on yield, earliness, host-plant resistance to pests and diseases, etc.

Challenge 7. Evolving cropping systems through modified or innovative practices

In many countries, cultural recommendations have changed little in recent years, as have the practices of cotton producers. Faced with climatic hasards, adaptation of the sowing period is often the only adjustment factor. However, other technical means can also be used to deal with CC, such as direct seeding under plant cover (DMC) and agroecology, or even agroforestry. They allow better management of soil cover and organic matter, with positive effects on water retention, erosion, nutrient availability and carbon storage.

Challenge 8. Developing and disseminating varieties adapted to CC

The constraints associated with CC imply the creation and availability to producers of varieties adapted or resistant to the effects of disturbances: shorter crop cycle, lower transpiration, thicker leaves, better conversion efficiency of radiative energy, better resistance to high temperatures, more developed root system, architecture adapted to high crop densities. Heat tolerant climate-resilient varieties retain a greater proportion of bolls despite rising temperatures providing high productivity under adversity.

According to the International Cotton Advisory Committee (ICAC, 2021), “Analysis shows how rain-fed, non-GMO, non-hybrid, short- season, high-density cotton varieties could double yields and farmer income; avoid pink bollworm infestation; and reduce insecticide use and induced pest outbreaks."

Challenge 9. Producing quality seeds

Controlling seed production is essential to ensure both genetic and germline quality. The former guarantees the conformity of the variety's characteristics, particularly in terms of its adaptation to growing conditions in relation to the CC (see Challenge 7). The second ensures that the crop emerges evenly and quickly, which is a factor in adapting to CC, while reducing the amount of seed needed per unit area. The establishment of a production chain for delinted seeds is also a factor in improving the germination rate, grading for vigour and optimising seed treatment. This type of seed also makes it possible to develop mechanical seeding, which helps to reduce labor, improve plant stand, the density of plants per hectare and yield, and increase the area sown.

Macro-challenge 3. Improving the economic profitability of the sector

At the producers' level, margin after payment for inputs is only about 200 USD/ha on average in Africa, with a strong variation according to geographical areas and producers (from less than 150 to more than 350 USD/ha). At processors'level, the challenge is to improve or preserve the quality of production and to increase the share of production processed locally (yarn, fabric, clothing, etc.).

Challenge 10. Increasing the profitability of production

Africa has the lowest average yields compared to other production areas in the world (400 kg fibre/ha compared to 800 for the world average). The challenge is to increase the profitability of production by, on the one hand, improving the seed cotton yield in the field for the producers and the fibre yield and quality for the ginner, and, on the other hand, reducing production costs, relying in particular on adapted varieties and seeds, evolving more efficient and/or less costly cultivation practices, and better training the stakeholders.

Challenge 11. Promoting access to financing

The development of cotton production in Africa requires improving access to agricultural equipment, agricultural practices and their efficiency and, ultimately, yields. In order to do this, producers must be able to access financing for i) the acquisition of inputs (mineral fertilisers, synthetic or biological pesticides) and ii) the production of organic fertilisers, in particular for crops that are rotated with the cotton plant, iii) the acquisition and care of draught animals, iv) the acquisition, use and maintenance of the necessary agricultural equipment, in particular in relation to the development of mechanisation (see Challenge 11).

Challenge 12. Developing mechanisation of cultivation and the establishment of 'cooperatives' for the use of agricultural equipment

Cotton cultivation remains largely manual or by plowing in developing countries. In a context of labour scarcity, mechanisation or motorisation of cultivation operations, from sowing, weeding, agrochemical application (fertilisers, herbicides, insecticides), and harvesting, would make it possible to improve profitability (in connection with Challenge 9) and to reduce the drudgery for labourers, producers and their families. Mechanisation of harvesting will also have consequences on the quality of production (see Challenge 12). The development of this mechanisation is, however, dependent on factors such as sufficient farm or plot size, training in "new trades" (tractor operator, mechanic, etc.), access to suitable machinery and tools, availability of suitable seeds, dissemination of suitable varieties, machinery maintenance, introduction of defoliant chemicals, pre-cleaners and technical itineraries, etc. Howeover, the introduction of heavy machinery leads to greenhouse gas emissions and to the displacement of farm labourers.

Challenge 13. Improving and enhancing the quality of fibers and seeds

West and Central Africa (WCA) produces a fibre whose technological quality is recognised. It is increasingly competing on the world market. In order to meet and anticipate the needs of processors, and thus maintain a comparative advantage, improvements (genetic, agronomic, technical, industrial, etc.) must be pursued and better valued on the international market.

WCA cotton, sold by each producing country according to its national sales types, is not promoted on a regional scale. Specific actions, developed by cotton companies or countries, are often limited by lack of means. Placing these promotional actions at the WCA level would probably allow them to have more impact. And the "African" quality standards for cotton lint, which are insufficiently valued, could be the basis for this promotion (Diop & Bachelier, 2006).

On the other hand, the envisaged development of mechanical harvesting will lead to the integration of more foreign materials or contaminants into the seed cotton, requiring more thorough cleaning in the ginning factories, which is more aggressive for the fibre. A possible consequence is a negative impact on its quality (intrinsic characteristics, foreign matter load), leading to a less remunerative price on the international market, and even to a loss of customers.

Finally, at the seed level, improvements can be envisaged by conventional selection to increase their oil or protein content. Recent advances in biotechnology makes it possible to block the synthesis of gossypol, a metabolite that is toxic to monogastric animals, and improving the feed value of cottonmeal.

Challenge 14. Providing tools to buffer the effects of price volatility

World cotton fibre prices follow the law of supply and demand, often with a downward trend, and are distorted by subsidies from developed countries. Production on the African continent, which represents less than 10% of world production, has practically no influence on world prices. The farmgate market price of seed-cotton for African producers is therefore often low and leads some to turn away from cotton growing, in favor of cashew nuts or other cash crops, which are more remunerative, or less demanding. To maintain the attractiveness of cotton production, price stabilisation funds or minimum support price guarantees have been set up in the past in certain African countries. Consideration should be given to the appropriate tools to be put in place nowadays to guarantee a stable income to producers and to improve the attractiveness of cotton cultivation in a competitive context.

Challenge 15. Increasing the share of processed production on the African continent

A large part (87% in 2021/2022 according to the ICAC, 2022) of African cotton fibre is exported outside the continent without processing, in the form of bales. However, the value added in relation to raw fibre (base 1) is 2 for yarn, at least 4 for printed dyed fabric and more than 8 for made-ups and clothing (COMESA, 2009). A very large part of the value added in the cotton sector is therefore captured outside Africa. Many textile companies (spinning, weaving, clothing) that existed in the past on this continent have disappeared and artisanal processing remains very marginal. Despite several attempts to revive this industry, and the posting by several studies of ambitious objectives for local processing, several obstacles persist: high cost and irregularity of energy supply, political or security instability, lack of transport infrastructure, lack of incentives or support for investment, etc. According to UNCTAD (2014), fiscal and investment policies should be harmonised, regional investment funds should be set up, and South-South partnerships should be encouraged to create an incentive environment for local processing.

Challenge 16. Creating farm revenue opportunities through value addition of farm waste and by-products

Cotton farms produce farm waste and by-products that can otherwise provide additional income to farmers when processed for value addition to be used as feedstock, food or feed. Cotton stalks are generally burnt or wasted in Africa. Cotton seeds are also either underutilised without subjecting them to scientifc oil extraction and use of seed-cake as animal feed. Cotton stalks can either be converted into compost, biochar or bio-fuel briquettes or pellets that are considered as sources of renewable energy to substitute forest wood and fossil fuels.

Macro-challenge 4. Contributing to the well-being of the sector's actors and their families

Taking into account and improving the social dimension (in all its components) is a *sine qua non* condition for advancing sustainability at the different stages of the value chain: production, ginning, processing, garment making.

Challenge 17. Planing and implementing research and support operations for the benefit of cotton farms

Currently, the global approach of the farm, for the production of knowledge, decision support and agricultural advice, remains weak. This approach requires multidisciplinary cooperation (including social sciences) and better interaction between researchers and producers. The implementation of participatory and co-construction tools is a step in this direction.

Challenge 18. Transfering, sharing and disseminating knowledge and technical innovations

The aim is to accelerate the transfer, sharing and dissemination of knowledge and technical innovations between research, support services and producers, as well as between farms of different sizes (small, medium, large or managed) to enable them to have access to innovations implemented at other levels and thus promote their development. This approach requires the creation and dissemination among producers and support services of technical materials, as well as the implementation of appropriate trainings in the field. The rapid adoption of mobile smartphones in Africa and the advent of recent technologies such as artificial intelligence create new opportunities for the efficient transfer of agricultural technologies even to less literate farmers located in remote areas.

Challenge 19. Contributing to reduce food insecurity

In Africa, according to AFD (Vincent, 2018), “cotton cultivation is the keystone of diversified production systems in which food crops, including cereals, play a dominant role. There is an interdependence between cotton production and certain major food crops such as maize. Preserving the balance between cotton and food crops therefore appears to be a fundamental issue in most producing countries”.

Cotton cultivation is an important vector for the dissemination of technical progress and innovation, and allows for the accompaniment of food crops with which it is rotated (maize, millet, sorghum) within the farms. Cotton thus contributes to the increase and diversification of farmers’ income and, thanks to food crops, to the reduction of food insecurity and even to their food balance (Soumaré *et al.*, 2021). Changes in the organisation of the cotton sector are therefore capable of reducing food insecurity. Cotton is a commercial cash crop that provides employment on the farm and throughout the post-production value chain. Increasing production and enhancing profitability create opportunities for better livelihood and food security.

Challenge 20. Improving working conditions at the different stages of the sector

The cotton sector is a source of work in the field or in industry for several million people throughout the world, from production to distribution, including processing and garment making. For many farmers and workers, particularly in developing countries, the income from the crop, wages and working conditions (hours, pace, drudgery, health and safety) are often the focus of criticism.

Challenge 21: Ending forced child labor

Article 32 of the International Convention on the Rights of the Child states that “States Parties recognize the right of the child to be protected from economic exploitation and from performing any work that is likely to be hazardous or to interfere with the child's education, or to be harmful to the child's health or physical, mental, spiritual, moral or social development.”

In the cotton sector, from the field to the textile factories, respect for this Convention must be the rule and the education, health and development of children must be priorities. However, situations of forced labour or, worse, modern slavery in cotton-producing areas are still reported by the media. Putting a definitive end to this is a major challenge, often with political and economic leverage.

Challenge 22. Promoting gender equity and equality

This aspect of the social pillar of sustainability concerns primarily the situation of women and youth. At the level of cotton production, it is a question of promoting the place of women within cotton producers' groups and as members of their offices, of ensuring equal remuneration for casual labour between women, men and young people on a cotton farm, and of ensuring access for all to functional literacy (FAO-ICAC, 2015).

Challenge 23. Ensuring good governance of the sector

In Africa, producers are highly dependent on cotton companies, whether public or private. Good governance necessarily requires a clear and transparent mode of operation, shared and recognised, involving all stakeholders and defining the roles and responsibilities of each. These are producers, through their organizations (POs), cotton companies (supervision, collection, ginning, crushing and marketing), interprofessions, research structures, possibly seed companies and State services, *etc.* The weight of POs and inter-professions has increased since the 2000s and they now directly take charge of certain activities or responsibilities within the sector such as the marketing of seedcotton or the financing of cotton research.

Challenge 24. Securing access to land

In Africa, many producers do not own the land they cultivate and do not have the guarantee of being able to work on it for several years in a row. Under these conditions, they have little interest in investing in this land, for example in the form of improving soil fertility or anti-erosion measures. This situation does not only concern cotton cultivation, but is frequently encountered in the cotton zones.

Securing access to land, either through the acquisition of property titles or through the recognition of a right of use gives producers a vision and security of tenure in the medium or long term, encouraging them to invest in and improve the plots to which they have access. The search for local solutions, often customary in Africa, can also allow for reasoned, peaceful and sustainable management of resources and space, by addressing the problem of animals roaming in the fields, a recurrent source of conflict between farmers and livestock keepers.

Macro-challenge 5. Developing the production of “identity” or preferred cottons

As consumers become more aware of the consequences of their purchases, the demand for “identity” products (organic, ethical, sustainable, of controlled origin or quality, *etc.*) is a fundamental trend that is expected to increase in the future. The cotton sector is directly concerned, and must continue and expand the development of products labeled according to their mode of production (*e.g.* “organic” fibre, oil and cosmetics) or their origin (*e.g.* Cotton made in Africa, CmiA). Potentially, this type of product has a good image and high added value.

Challenge 25. Strengthening research and technical support for organic production

According to ICAC (2021), "An analysis of the global status of biotech cotton, organic cotton and hybrid cotton concluded that organic cotton had more potential forgrowth due to increasing consumer demand". And according to Textile Exchange (2021), "Global organic cotton production grew an impressive 56% in 2017/18, far exceeding the 10% growth rate of the previous year".

Although growth expectations are high, organic cotton production remains very low in Africa (presently only in Tanzania, Uganda, Benin, Burkina Faso, Mali and Senegal). The short-term needs and issues on which research and development (R&D) must focus concern the development of adapted varieties and technical itineraries, the availability of organic seeds,the identification and sourcing of locally available organic inputs, the local production of bio-control, biopesticides, biofertilisers, compost and manures, the identification of a specific procedure (from the field to marketing), the implementation of registration, monitoring, auditing, certification, traceability and labeling tools, *etc.*

Challenge 26. Implementing a technical organisation of cotton companies to empower the organic sector

In some African cotton-producing countries, the low level of organisation does not allow the valorisation of organic production as such, mainly because of mixtures with conventional production. Hence the need to set up a system allowing the coexistence of the "organic" and conventional sectors. The creation of a specific "organic" sector should thus allow for specific and differentiated monitoring at the production, collection, transport, storage, ginning and marketing levels, recognised by a certification and/or a label and resulting in a better valorisation.

Challenge 27. Establishing the conditions necessary for the development of preferred "identity" chains

The technical development of specific commodity chains, particularly those that are more sustainable (organic, agro-ecological, ethical, *etc.*) must be supported at the political, regulatory and economic levels.... This includes the development of the necessary tools for traceability (certification, labeling), the setting of attractive purchase prices, access to credit for inputs, financial support during the conversion period if necessary, and promotion of production to consumers.

Challenge 28. Valuing co-products of organic cotton production and products of associated crops

The production of cotton fibre for the textile market is accompanied by the production of co-products such as oil for human consumption and cosmetics, oil cakes for livestock feed, and sometimes short fibre and linter. In conventional production in Africa, these low-value co-products are generally intended for local markets. In "organic" production, they could be better valorised, especially for export. The same is true for the products of crops, mainly food crops (millet, sorghum, legumes, *etc.*), that are grown in rotation with cotton in organic farming systems. Many cropping systems provide advantages of providing additional revenue, supplementing food and feed, increasing soil fertility, and supporting ecological engineering to maximise naturally occurring biological control to minimise pestilence.

Challenge 29. Developing specific product properties or applications

Cotton fibre has natural properties that allow to create fabrics that are appreciated by consumers: hypoallergenic, soft, insulating, absorbent, comfortable, able to withstand heat well, and washable at high temperatures. On the other hand, cotton fabrics take longer to dry and wrinkle more easily than some synthetic fibres. And as with other fibres, the dyeing and printing stages are potentially very polluting. To meet competition from other fibres or specific demands, work could be carried out on the development of naturally colored cotton fibres (there are already ranges of green and brown colors), requiring less maintenance (“easy care”) or containing molecules with prolonged release (anti-transpiration).

By using cottonseed, and in particular the proteins it contains in large proportions (around 25%), it has been demonstrated that it is possible to create biodegradable films. These could be used, for example, to coat seeds (including mineral elements or active molecules) or to make mulch films to protect crops (by reducing evaporation and competition with weeds).

Macro-challenge 6. Strengthening research and development structures, actors and actions

Research and development (R&D) activities must anticipate and accompany the evolution of the sector. However, in a context of scarce human and financial resources available to maintain structures and conduct effective and relevant activities, it is essential to create synergies between them. This is all the more justified when the agro-pedo-climatic situations are of the same nature and the parasite, fertility or varietal problems are convergent, as is the case today for the majority of African cotton-growing countries.

Challenge 30. Strengthening regional and international research and development infrastructures and collaborations

Currently, the Regional Program for Integrated Cotton Production in Africa (PR-PICA) is the only functional R&D network in West and Central Africa. Bringing together cotton companies and inter-professional organisations, cotton research structures and cotton producers' organisations, it focuses on pest control, soil fertility and adaptation of cultivated varieties to CC. At present eight West and Central African countries (Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Mali, Senegal and Togo) are members.

ICAC set up a Southern and Eastern African Cotton Forum in 1996, which held 14 biennial meetings in different countries to discuss and develop collaborative research projects and cotton developmental programmes. The role of these two entities should be strengthened and consolidated, and even expanded. In addition, exchanges at the continental scale between these two networks should be encouraged.

Challenge 31. Supporting the generational transition in the research sector

The national agricultural research structures (NARS) as well as certain international research centers (CIRAD, *etc.*) working on cotton are experiencing or will very soon experience a major wave of retirements. To ensure the transition and not lose the basic skills and knowledge of senior researchers, it is essential to rapidly recruit young researchers and technicians. They will have to be accompanied by their elders who will ensure the transfer of this “cotton research heritage”.

In addition, the evolution of methodological approaches and technologies, innovative and more efficient but more demanding and specific, touch on all scientific disciplines: agronomy, genetics, crop protection, sociology, economics, *etc.* New strategies and tools are available and they require the mastery of new skills for junior researchers, in addition to those transmitted by senior researchers. It is therefore a twofold challenge: to transfer current skills to the new generation, through initial training, and to enable them to acquire new skills, through continuing education, to meet the new challenges of the sector.

Challenge 32. Developing demand-driven approaches based on the co-construction of references

In a production context and environment that is changing more rapidly due to global changes (CC, pressure on agricultural land, soil degradation, *etc.*), R&D cannot be conducted unilaterally. It must necessarily take better account of the needs and constraints of producers, as well as their knowledge. To do so, it must rely on approaches such as the co-construction of technical solutions, the implementation of participatory approaches, the integration of local knowledge, the taking into account of gender, *etc.*

Challenge 33. Acquiring updated elements for forecasting and steering the sector

In order to foresee and anticipate future orientations in terms of R&D for the cotton sector, it is necessary to identify sufficiently upstream and sufficiently early the evolution of needs, demands, constraints, opportunities... at the level of the different stages and the different actors (producers, processors, consumers). A good knowledge of the world market and its trends is essential, and relies on strong relationships with its actors. On this basis, it is possible to advise public policies and contribute to the strategic orientations for the sector

Macro-challenge 7. Improving the image of the cotton sector among the population at large

Although cotton is a natural fibre, as opposed to artificial or synthetic fibres, it is increasingly being attacked from an environmental, economic and social point of view at the various stages of its production chain. The actions implemented to improve its sustainability throughout these stages and the associated objective figures must be communicated and shared with consumers and, more broadly, with the civil society in order to restore a more positive reality.

Challenge 34. Communicating sustainability indicators for cotton production in Africa

Indicators have been developed by the ICAC SEEP panel and adapted to the production conditions of small-scale rainfed agriculture in Africa. However, they are not (or not very) well known to producers' organisations, cotton companies or interprofessions, and therefore used or shared. The positive elements of African cotton production, in comparison to that of other geographical areas, are not highlighted, nor is the progress made in recent years to improve sustainability on this continent. It could be worthwhile, in the long run, to communicate each year in a transparent and accessible way (information note, website...) on the strong points, the improvements obtained compared to the previous year, and the targeted improvements for the following year. African cotton is mostly rainfed and is characterised by the lowest use of agrochemical inputs in the world, resulting in some of the lowest levels of greenhouse gas emissions and low disruption of biodiversity. There is an imminent need to measure and quantify sustainability metrics of African cotton production systems to place it in a global perspective, thus giving it a great competitive advantage on the global markets.

Challenge 35. Establishing the comparative advantages of cotton fibre production over other textile fibres

Cotton fibre is currently the second most important textile fibre in the world, ranking behind synthetic fibres derived from petrochemicals, but ahead of artificial fibres (mainly cellulosic) and other natural fibres (wool, silk, *etc.*). In order to establish the impact of the cotton industry, compared to that of other textile fibres, it is necessary to take into account many elements at the production and processing levels (consumption of inputs and water, environmental discharges, remuneration, ethics, health and safety aspects, *etc.*). Important differences also exist between cotton production areas, especially when looking at the specific case of family, rainfed and conventional cotton production in Africa. Better communicating good practices and emphasising the contribution of cotton to the sustainability of family farms, carrying out comparative life cycle analyses, in particular those of “identity” cottons (see MC 5) could help reposition the cotton fibre to its true value. Agricultural production systems emit greenhouse gases, but they also absorb huge amounts of atmospheric CO_2 to sequester significant quantities of carbon in the soil. There is a need to quantify the net carbon footprint of cotton production systems in Africa, to include carbon sequestration rates, that would in all likelihood establish a climate-positive case for African cotton.

Conclusion

Although these 35 challenges are the basis for its cotton roadmap, CIRAD does not have the ambition, or the means, to respond to all of them. The priorities for its future research and development actions and projects over the next 10 years will be based solely on the challenges for which it has the capacity and legitimacy to respond with its partners.

The challenges presented in this paper have mainly been identified with the aim of cotton production for sustainable family farming in Africa. They are therefore not intended to be an exhaustive list. However, several of these challenges have a wider scope than this continent alone and need to be addressed at global level, possibly through international collaboration.

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An entomopathogenic fungus recently discovered to attack *Amrasca biguttula biguttula* (Hem.: Cicadellidae) in Benin: provisional identification and research to be undertaken

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Abstract:

In June 2023, high populations of *Amrasca biguttula* were observed in Cotonou, Benin, infected by an entomopathogenic fungus on leaves of *Abelmoschus esculentus* (okra). This first reporting in Africa could be due to an Entomophthorale. Recommendations are given to better identify the fungus.

Keywords: okra, leahopper, Entomophthorale, Sub-Saharan Africa.

Introduction

The leafhopper *Amrasca biguttula biguttula* (Ishida) (= *Amrasca devastans* (Distant)) (Hemiptera- Cicadellidae), known as the Green or Indian cotton jassid, has recently been observed as an invasive exotic species on cotton plants in many West African countries as well as in Madagascar. During a mission carried out in southern Benin in June 2023, high populations of this insect were observed on the leaves of okra plants (*Abelmoschus esculentus*, Malvaceae) grown at the headquarters of the Institut National de Recherche Agricole du Bénin (INRAB), and close to the International Institute of Tropical Agriculture (IITA), in Calavi (outskirts of Cotonou). Dead adults, golden yellow in color, attached under the leaves of all varieties, with their wings spread apart (Figures 1 and 2) were suspected to be contaminated by an entomopathogenic fungus.

Figure 1. Dead adults of A. biguttula *on okra leaves (lower parts). © P. Silvie, CIRAD*

Figure 2. Dead adults of A. biguttula *on okra leaves (details). See the spread wings, an indication of probable fungal infection. © P. Silvie, CIRAD*

Provisional Pathogen Identity

The examination under a binocular microscope of the samples brought back at IITA's laboratory allowed us to observe the presence of granular particles of the conidia type on the wings of some individuals (Figure 3).

These particles suggested that the fungus must belong to the *Entomophthorales* group. Insects who had already sporulated were placed on water-soaked cellulosic paper placed in the lid of a Petri dish to obtain conidia by projection (according to the methods described by Silvie and Papierok (1991)). This operation yielded conclusive results on Wednesday evening, with conidia having been projected onto the slides. With a rotund shape, they may belong to a species of the genera *Conidiobolus*, *Entomophaga*, or *Batkoa*. The confirmation of the leafhopper's identity was done molecularly on healthy individuals collected in parallel.

Figure 3. Adult of A. biguttula *with spread wings viewed with a binocular. Note the rounded conidia of the fungus projected onto the wings, a characteristic feature of the Entomophthorales group. © G. Goergen, IITA*

A comprehensive literature review gave rise to a well-founded hypothesis regarding the identification of the pathogenic species. Thus, the fungus *Batkoa amrascae* Keller & Villacarlos, described by Villacarlos and Keller in 1997, was observed to infest *A. b. biguttula* in the Philippines thirty years ago (in 1993). More recently, in India, the same species was reported on *Cofana spectra* (Hem.: Cicadellidae), an insect present in the "rice system" (Baiswar and Firake, 2021) which Keller and Yubak Dhoi had suspected as early as 2007, but on another Hemipteran insect, *Pyrilla perpusilla* (Fulgoridae), occurring on sugarcane and collected in September 2000. Fungi from the Entomophthorales group, especially the species *Zoophthora radicans* (McGuire et al., 1987; Butt et al., 1988; Galaini-Wraight et al., 1991; Wraight et al., 2003), are also known as pathogens of species of the Cicadellidae family (Batista Filho et al. 1997; Souza et al., 2021).

Research needs

To confirm the hypothesized species, it is imperative to measure both primary and secondary conidia, which should be spherical in shape. The presence of rhizoids—filaments that attach the cadavers to leaves—must also be verified, along with the number of nuclei in the conidia, using staining methods such as lactophenol-aceto-orcein (0.5%) or cotton blue and orcein. Additional morphological attributes that need to be verified include the conidiophores, which should be simple and unbranched, as well as the form of the hyphae.

The occurrence of this pathogen should be further investigated in populations found on cotton plants. If present, its role should be considered in any study on the population dynamics of the leafhopper, as epizootics are frequent when specific humidity conditions are met - specifically, several hours of 100% relative air humidity per night. Rainfalls recorded in Cotonou in June 2023, combined with the high leafhopper density on okra plants, undoubtedly facilitated the observed epizootic event.

The species *B. amrascae* can be cultured in artificial media. If indeed present in Benin, the species should be isolated for two main purposes: firstly, to further characterize the species, and secondly, to explore the possibility of infecting *A. b. biguttula* populations in other humid regions of the country. For instance, trials could be conducted in lowland areas cultivated with okra during the dry season, provided the insect is abundantly present. Another strategy could involve the collection of okra leaves infested with mycosis-affected dead individuals for direct dissemination into living leafhopper populations. However, it should be noted that manipulating this group of pathogens is challenging, and large-scale fermentation culture is probably not economically viable at time.

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Towards an Early Warning System for cotton pests in Benin using long-term and multilocal observational data

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Abstract

Controlling pest populations in cotton fields is crucial to reduce yield losses due to plant damage. However, knowing the economic, environmental and agronomical issues related to the systematic use of chemical insecticides, it is urgently needed to better assist spraying decisions based on the development of an Early Warning System. In Benin, one of the major cotton producers in West Africa, a comprehensive annual monitoring of the incidence of key pests has been implemented for more than ten years. Here, we propose to use these long-term and multilocal observational data to (1) better understand the relationships between environmental variables, including climate, landscape context, but also crop management, and intra- or inter-annu al pest population dynamics within the cotton-growing area, and to (2) better predict the risk of yield loss due to key pests as to better target interventions. As a perspective, we suggest developing standardized data collection and management throughout the West-African cotton-growing area for areawide pest management.

Keywords: cotton, Early Warning System, IPM, *Helicoverpa armigera*, modelling.

A need for better pest control strategies

Insect pests are a major obstacle to the increase of cotton production in West Africa, leading to 25-35% yield losses annually (Amanet *et al.*, 2019; Brévault *et al.*, 2019). Recently, outbreaks of the invasive jassid species, *Amrasca biguttula*, have highlighted the need for monitoring systems for rapid intervention (Kouadio *et al.*, 2022). Other key pests such as the cotton bollworm, *Helicoverpa armigera*, must be closely monitored because of their potential impact on cotton production.

In West Africa, pest control is primarily based on the use of chemical insecticides (Mutsaers *et al.*, 2022). Pest management programs recommend to farmers to spray cotton plots on a calendar basis (Silvie *et al.*, 2013), regardless of pest incidence. If this strategy has enabled the cotton value chain to maintain yields across years (Mutsaers *et al.*, 2022), some important drawbacks can be noted:

- Target imprecision: Insecticidal sprays are sometime unnecessary because targeted pests are not present.
- Timing imprecision: Because products are sprayed on a 14-day calendar basis, pest outbreaks can occur in between two treatments.
- Economical cost: Multiple applications can become costly for farmers over a full cropping season.
- Environmental health cost: Chemical insecticides are responsible for detrimental impacts on ecosystem health and biodiversity in and around fields (Van Der Sluijs *et al.*, 2015).
- Human health cost: Chemical insecticides represent an important health hazard for farmers using them regularly and in large amounts, particularly when they are poorly trained to use them safely (Gouda *et al.*, 2018; Vikkey *et al.*, 2017).
- Resistance evolution: Surviving individuals can carry resistance alleles increasing their frequency in populations over generations, thus leading to pest control failures (Kranthi *et al.*, 2002; Wu & Guo, 2005).

Considering such limitations, pest management strategies should evolve to contribute to more sustainability of cotton-growing systems. Spraying decisions should be triggered dynamically according to the abundance of pest populations in the field and potential associated damage to the crop and yield loss. Such management requires high skill level of farmers and technical advisors. They should be able to sample and identify a diversity of insect pests to take the decision of spraying and to select as specific and environmentally friendly insecticides as possible. Ideally, pest sampling methods and associated intervention thresholds for each target pest could assist decision to spray at the right time according to pest abundance (Silvie *et al.*, 2013). However, yield loss due to insect pests also depends on agronomic factors such as crop phenological stage (Schellhorn *et al.*, 2015), potential of plant compensation (Brook *et al.*, 1992), potential of biological control (Keasar *et al.*, 2023), and co-occurrence of other pests. Thus, intervention thresholds should vary across the cropping season and across fields to consider these factors. Obviously, deploying such a decision system for a cotton production basin might be complex and costly, because it would need many observations as well as training programs to take accurate and relevant decisions at the plot scale (Silvie *et al.*, 2013).

Towards an Early Warning System

Early Warning Systems (EWS) can help overcome this issue (Davies *et al.*, 1991). An EWS is a system that can predict the risk associated with a specific pest or a cohort of pests at a given spatial and temporal scale. The risk is estimated without the need to evaluate pest abundance in the field. It is often based on models predicting insect abundance, date of first occurrence, or daily probability of overpassing the threshold. Risk estimations can be automated and performed at different spatial (field, city, district, *etc.*) and time (daily, weekly, *etc.*) scales. The model can be either statistical or mechanistic. In any case, the prediction will be made based on easily measurable variables. Climate variables are usually critical in predicting pest risk. If climate previsions are available, EWS can predict a risk. EWS can thus greatly help insecticide spraying decisions against the right pest at the right time and the right place. As such, it has the potential optimize spraying decisions at a large scale.

Benin is one of the countries with highest cotton production in Africa (Food and Agriculture Organization of the United Nations, 2023). To better monitor spatiotemporal pest population dynamics, the National Institute for Research on Cotton (IRC) has led a comprehensive program to sample pest populations at the country scale from 14 experimental stations distributed over the territory (Figure 1). In each station, the abundance of key pest species has been measured weekly since 2010 with a standardized protocol. A database has been compiled from all the data collected on experiments at stations and on farmer fields. It has been primarily developed to monitor the pest pressure throughout the growing season over the cotton-growing area and to realize yearly assessments of the performance of the recommended spraying program. A supplementary design has been set up since 2018 on 100-300 farmer fields sampled within the cotton production basin.

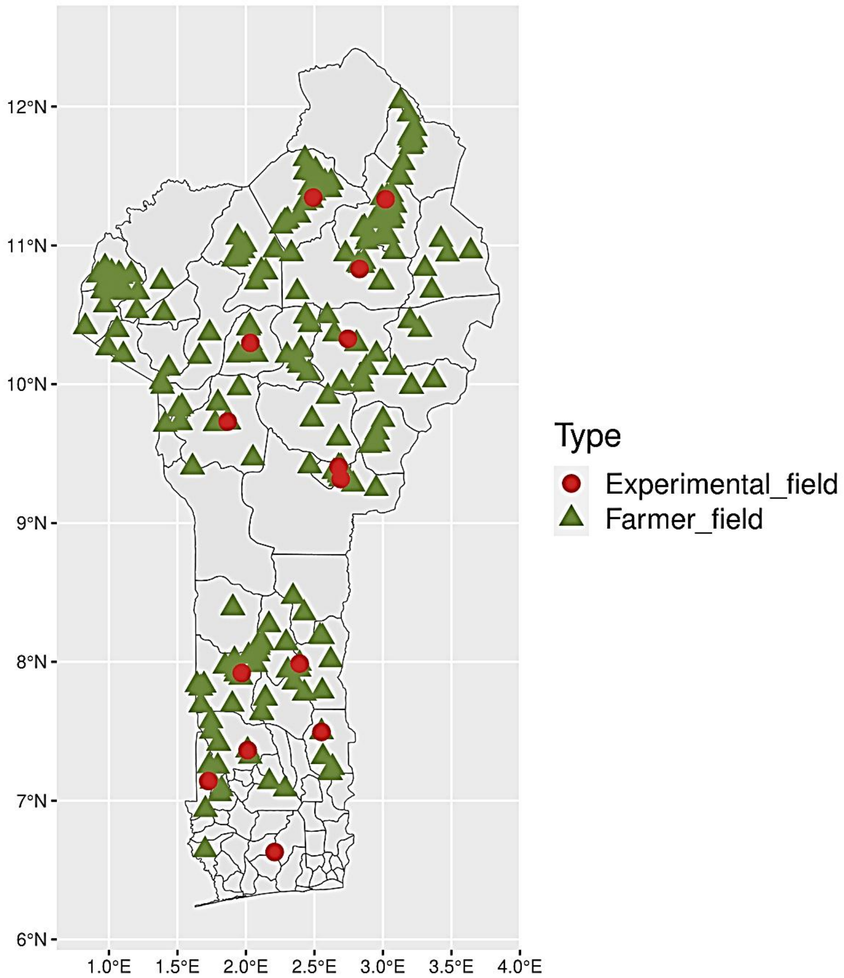

Figure 1. Distribution of fields sampled by the Institute of Research on Cotton (IRC) in Benin in 2023. Red dots represent sampling in experimental stations. Green triangles represent farmer fields.

A project has been launched in 2022 to capitalize this multi-year and multi-site dataset to better identify the determinants of pest outbreaks from a seasonal to decennial temporal scale, but also to predict pest risk using statistical modelling. This project targets two main outputs:

1. Automated representation of real time pest abundance on maps based on weekly field observations on experimental stations and farmer fields. Monthly maps are given in figure 2 for the sake of illustration.
2. Early prediction of pest risk based on a statistical model relying on environmental variables (*e.g.* meteorological variables, landscape context) and crop management (*e.g.* sowing date). This system will be able to produce risk predictions up to one week in advance.

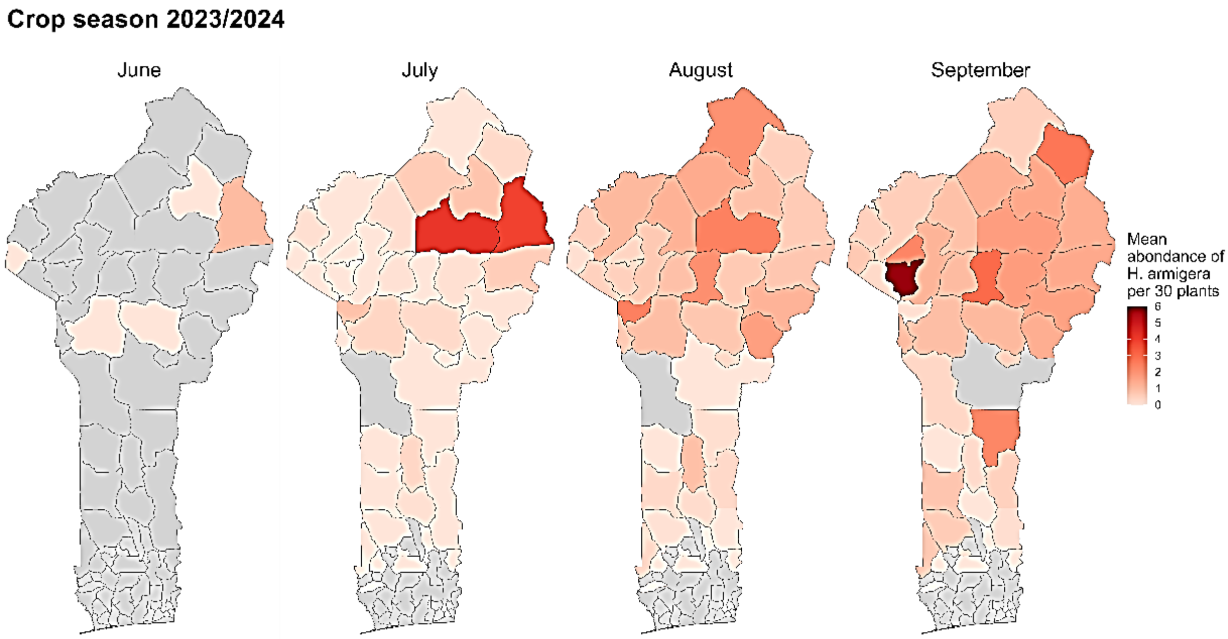

Figure 2. Spatio-temporal evolution of H. armigera density (number of larvae per 30 cotton plants) across months and counties in 2023.

Information will be aggregated at the county level. Among the 13 pests present in the database, *H. armigera* is probably the species of most concern regarding yield loss. As such, the early prediction system will be developed on this pest. On the longer run, the process could be adapted to other pests according to their relative importance in terms of yield loss. An online platform will be then developed to give stakeholders access to such information.

In the case of a large-scale deployment of such early warning system, it is essential to discuss in advance with potential end users to define the nature of the information that will be delivered, and to detail the specifications to be made before its development. Here are some crucial points to focus on:

- Objective. An EWS is developed with an applied objective for crop management.

One could be seeking to decrease the frequency of insecticide spraying or to simply concentrate them in an optimal window of time for increased efficiency. This point is central because it conditions the others.

- Choice of the risk variable. Risk can be defined very differently from pest to pest depending on their biology and type of damage. Some insects present a continuous threat for the crop yield by their occurrence, while others are only detrimental during a specific phenological stage of the crop, or when their abundance reaches a certain threshold. Here, one could choose to represent the risk by a daily probability of occurrence, an index based on the probability of occurrence and the phenological stage of the crop, or the probability for the insect abundance to reach a threshold beyond which the risk of yield loss is greater than the cost of one insecticide spraying. The risk level can also integrate agronomical, biological and strategic considerations in accordance with the objective previously defined.

- Spatial and temporal scales. It is necessary to define the resolution at which the EWS will represent the risk. When the EWS is based on a model relying on external variables, the precision is constrained by the granularity of available data. For instance, meteorological data are often collected through synoptic stations. They are distributed in space and have a certain time resolution. They usually collect daily data. In this case, it is not possible to predict a risk for less than a day, and with a spatial precision less than the number of stations per unit of area. Thus, scales are also responsible for part of the uncertainty associated with the risk estimation. This uncertainty becomes more important when predictive variables strongly fluctuate in space and time.

- Targeted audience. An EWS can target different audiences, usually either farmers, field advisors, decision makers or a combination of them. In any case, the audience should be trained to be able to properly interpret and analyse EWP outputs. The understanding of how the risk is represented, how the calculation is made, and the level of uncertainty associated with it is crucial for a rational use of the outputs.

Towards better understanding of pest bioecology

The exploration of this database will also deliver precious information about spatial and inter and intra-annual population dynamics of pests.

Hypothesis 1. The population dynamics of the cotton bollworm, *H. armigera*, is probably driven by the area of cotton in the agricultural landscape, but also of alternative host plants (e.g., maize). We expect to find a significant and positive relationship between resource availability and *H. armigera* abundance (Cunningham & Zalucki, 2014; Riaz *et al.*, 2021).

Hypothesis 2. Knowing that *H. armigera* populations start to build up at the beginning of the rainy season in the cotton-growing area, the sequence of host plants is crucial for population growth or maintenance before cotton offers resources for larval development

(Brévault *et al.*, 2012). We expect to observe a lower density of this pest in cotton fields as long as alternative host plants are available in the agricultural landscape.

Hypothesis 3. Pest populations can be impacted by cultural practices such as the nature of insecticide sprays (Fanigliulo & Sacchetti, 2008; Men *et al.*, 2005), frequency and dose of applications, cotton varieties (Riaz *et al.*, 2021) or sowing date. We expect to detect long-term impacts of significant changes in pest management programs or crop management on the population dynamics of some key pests.

The validation of those hypotheses could open avenues for the re-design of pest management strategies. For instance, in relation to hypothesis 1, we know that maize is widely cultivated in Benin and that it is an important alternative host for *H. armigera*. Thus, a systemic control strategy should also involve maize crops as a potential source or trap crop.

Perspectives: a common effort to monitor pest populations

Beyond the development of an EWS, this work highlights the major importance of standardizing data collection over a long period of time, at large scale, for efficient valuation. Above all, the data needs to be cleaned, harmonised and structured in relational databases, so that it can be easily shared and made available to researchers and stakeholders. A second important lesson is that observational data must be completed by environmental variables such as weather, landscape context, and variables related to crop management (e.g., insecticide sprays in the case of crop pests). The quality and quantity of information will be key for analyses and predictions.

The database described here focus on cotton pests in Benin. Enlarging it to other West African countries could open new research avenues to better understand pest population dynamics at a regional scale. Area-wide strategies could also be considered over the entire cotton-growing area in West Africa, which would be particularly interesting in the case of long-distance migrating pest like *H. armigera*. Finally, developing a common monitoring program could also catalyse collaboration and concertation on pest management strategies among countries.

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