Review of *Urochloa* Breeder's Toolbox with the Theory of Change and Stage Gate System Approach

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Abstract

Livestock production in the global south is at crossroads as there is a demand to increase Animal Source Foods to address hunger and pressure to lighten the environmental footprint often associated with livestock production. To satisfy both needs, the use of technologies that improve animal performance, while reducing land use and net Greenhouse Gas emissions produced by animals is essential. One of such technologies are *Urochloa* forage grasses.

Urochloa forage grasses are well known for their rusticity and their ability to grow in soils of low fertility and high aluminium content. These characteristics allow *Urochloa* to grow in areas temporally or spatially less suitable for crop production, but also have made ruminants production profitable in areas that would not be otherwise. However, productivity and sustainability of ruminant production in these areas is likely to fall within the next decade due to climate change unless action is taken.

Despite these known benefits of *Urochloa* forage species, breeding programs have long delayed initiation due to apomixes and differences in ploidy. In the mid-1980s, the development of suitable sexual germplasm allowed crossings, and therefore favoured the emergence of breeding programs. In recent decades, several advances in biology, molecular biology, phenotyping, population genetics, genomics and transcriptomics have generated a plethora of information that ought to be integrated for its use in a single breeding toolbox. We use the Theory of Change and Stage-Gate systems approach to review these advances in research and the utility of the current and future available tools. Further, we address the remaining lack of information, thus bridging the knowledge gap and enabling us to maximize the genetic gain in the different *Urochloa* breeding programs. In this way, we identify breeding bottlenecks and help to pinpoint priorities for *Urochloa* research and development.

Introduction

A cornerstone of sustainable development is seeking solutions that solve more problems with fewer resources. One novel solution for issues like food insecurity, climate change, and soil deterioration is the use of improved forages. Improved forage grasses such as *Urochloa* hybrids, are considered a sustainable way to grow food, via feeding animals, in low fertile soils that would be otherwise unfit for planting crops for human consumption. *Urochloa* hybrids are an excellent source of animal feed (Baptistella et al. 2020) while also improving soil health (Horrocks et al. 2019). However, *Urochloa* research and development has been stifled due to the lack of understanding of needs among different stakeholders, as well as dearth of recognition.

In this paper, we explore what barriers exist to the advancement of *Urochloa* research, breeding and dissemination through an approach that combines the principles of theory of change (ToC) (CIAT 2019) with the principles of the stage-gate system (SGS) (Cooper et al. 2002). The ToC approach is a testable model of how and why change is expected to happen along an impact pathway in a particular context. Meanwhile, the SGS model is a methodology for conceptualizing, developing and commercializing new products. Considering the multisector nature of *Urochloa* research (research and development institutions such as the Alliance of Bioversity International and CIAT (the Alliance), national public development centers, private seed sector companies), using ToC and SGS helps to capture the nuanced roles of different actors and demonstrates the importance of multisector integration to address the lack of sufficient cost-effective, efficient and resilient forage options for the different markets in the tropics. Further, a ToC and SGS allows us to define which mechanisms ought to be implemented to contribute to outcomes (changes in behaviour because of activities, products and services) and the ultimate impact we aim to attain in a causal way, thus expressing the plan of action.

In using the ToC/SGS approach, our team contextualizes 1) the landscape of current *Urochloa* breeding; 2) outlines the changes we wish to see, in terms of outcomes and impacts; 3) provides a plan for how to obtain desired changes and; 4) states key actors involved in making the change. Ultimately, we explain how a public-private multi-sectoral approach aligned around a clear breeding development process could create and disseminate grass forage hybrids that are adapted to key regions and markets, thus helping to solve issues of food security, climate change and soil deterioration.

Methods and Study Site

The causal nature of ToC and SGS is useful for highlighting the breeding process that we use to examine the concrete steps needed to develop effective grass forage hybrids. As suggested by the SGS principles, the whole forage hybrid development process, from the new product idea creation to dissemination was fragmented in different stages (Product design, Pre-breeding, Breeding, Testing for Adaptation, Seed Production and Registration, Launching and Dissemination). For each stage, we identified key actors, inputs, outputs, and outcomes needed to ensure each of the stages throughout the development of new hybrids is satisfied, so that it is possible to create affordable, accessible, and approachable *Urochloa* hybrids.

Results

Stages and Gates of Urochloa Research

Next, we will describe the operation of the *Urochloa* hybrid research and development process, with the implementation of the proposed ToC and SGS. In the product design stage (Stage 1), we understand the final user needs and based on that, describe the traits that will be required in the desired final product. After a screening of ideas by a cross-functional team which evaluates the balance of magnitude of the "change expected" versus "cost and feasibility", several ideas of products are discarded but few are advanced to the next breeding stage. For instance, at the Alliance, one of the product lines that successfully went through this initial stage is the production of "interspecific *Urochloa* hybrids for the East African market (UHxEA), adding new traits (drought and spider mite resistance) to our already commercial hybrids". Then, during the pre-breeding (Stage 2), the source genetic material to satisfy the required traits needs to be identified within available genetic diversity units (genebanks or nature), and proper screening methodologies (phenotypic and genotypic tools) should be developed. Once sources of desirable traits and screening tools are available (Pre-Breeding), crossing different genotypes (Stage 3: Breeding) and testing (Stage 4: Testing for Adaptation) to attain those traits is crucial to ensure that the resultant hybridized materials are suitable in the target environment. If successful, it is possible to scale-up the seed production and registration of these hybrids (Stage 5), and finally impact is sustained by encouraging the use of forage hybrids as a means to address challenging development problems (Stage 6: Launching and Dissemination).

Stage 1: Product Design

In order to characterize the demand for forages, various desired biophysical qualities to describe the regions where the *Urochloa* forages are demanded (soil, biophysical characteristics of the various environments), as well as the socio-economic characteristics of the farmers in those regions (characteristics of target users) are identified. Then the information is logged into a centralized database and populated with data on suitable regions, consumer *Urochloa* preferences and needs, and suitable germplasms (for testing desired traits). By involving actors from developmental sectors, government agencies, and NARS (cross-functional team) to define these demands, we can not only socialize the importance of a centralized database but also identify *Urochloa* demands across various sectors. Access to a centralized database of information about different germplasms and genes (the building blocks for breeding) as well as demands (including consumer preferences, regional needs, and user needs) allows researchers to select the adequate traits and qualities for hybrid creation. Using the information and expertise collected, the cross-functional team filters and prioritizes the traits required in the desired product, which guarantee the satisfaction of a clearly delineated market segment in a document known as the product profile.

Stage 2: Pre-breeding

To respond to the market needs described in the product profile, biological sources of the required traits should be identified. For instance, as drought tolerance is requested in the UHxEA profile, a screening into the genetic resources is needed in order to identify potential donors of this trait, which can be used as founders/parents of breeding families/populations. Simultaneously, adequate methodologies to discriminate best genotypes for the desired traits should be created during this stage. These can be either phenotyping tools (like field or glasshouse high-throughput methodologies to test the performance under drought conditions in the case of the UHxEA profile) or genotyping tools (like genomic selection), which will allow researchers to identify best hybrids along the whole breeding process.

Stage 3: Breeding
Having adequate founders/parents, as well as phenotyping and genotyping tools in hand, allows recurrent cycles of crosses among desirable parents and selection of the best hybrid progeny, through a breeding process called recurrent selection which is carried out during the breeding stage. We prove efficiency by creating progeny of around eight thousand individuals and test them for various desired traits, followed by selecting grass forage hybrids with at least 1.5 overall genetic gain compared to local varieties.

Stage 4: Testing for Adaptation
The best performing hybrids from Stage 3 are tested in more locations in order to identify which hybrids are not only performing the best under Alliance research nursery and station conditions, but are also stable, resilient and promising in terms of seed production. At this stage, around 100 hybrids are tested in at least four locations representative of the target market, while only the best and most stable hybrids (around 10) are advanced to the next stage.

Stage 5: Seed Production and registration
If the regulatory environment is linked through participation of key enabling actors from a variety of sectors, and agreements of cooperation are secured, then the registration process is circumvented to allow for testing and adaptation, seamless dissemination in various biophysical environments and different productive systems. Technical information is consolidated and developed for seed production guidelines. Key partners help harmonize registration and certification and any outstanding grass forage hybrids (at this stage few hybrids are maintained in the pipeline, usually less than 10 promising individuals) are adapted to specific regions/markets and demonstrate improved performance.

Stage 6: Launching and Dissemination
With the support of public and private sector dissemination actors, information about the potential economic gains, as well as all required technical information to support the *Urochloa* implementation as forages are conveyed to farmers, the target users now understand the long-term gains of such investment. Financial, political and educational frameworks are functioning and support the adoption of *Urochloa* seeds in contexts of sustainable intensification.

Discussion
Understanding the needs and potential of all stakeholders involved along the *Urochloa* hybrid research-development and dissemination pathway could help make crucial improvements in *Urochloa* breeding as well as improving access and suitability of *Urochloa* seeds. Advancements in research through increased efforts and alignment among actors may make critical improvements for forage research, making dissemination easier, faster, and seeds better suited for the particular environment where it aims to be used. The higher the dissemination, the more effectively these hybrids will support rural livelihoods and some of the world's most vulnerable smallholders.

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