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REVIEW

Enabling cumulative learning in user-oriented research for root, tuber and banana crop breeding

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Summary

User-oriented research is important in breeding improved genotypes, for developing and validating product concepts (mostly involving trait prioritisation), as well as evaluating breeding products in use situations (mostly involving participatory variety evaluation). This paper examines key aspects that enable cumulative learning in user-oriented research for root, tuber and banana (RTB) crop breeding. We reviewed empirical user-oriented studies on RTB crops published between 1996 and 2020. We examined the ability of user-oriented research to foster cumulative learning by examining four key aspects: *spatial and temporal coverage*; *gender* aspects; the range of *traits* considered and *publishing practices* as evident in reports and datasets. We conclude that user-oriented studies have received attention in RTB breeding but fall short of enabling cumulative learning. Substantial investments in methodology development and capacity are needed to bring greater coherence to this field and enable cumulative learning about user perspectives to iteratively increase the fit between improved genotypes and user preferences.

Keywords: Farmer evaluations; Participatory research; Crop traits; Varietal selection; Literature review; Roots; Tubers; Bananas; Trait prioritisation

Introduction

User-oriented research helps plant breeding programmes in establishing goals to generate breeding products that accommodate end-user preferences (Goa and Ashamo, 2017; Weltzien and Christinck, 2017). User-oriented research is a crucial part of breeding product design and management, the process through which a new product is developed, tested/evaluated and introduced into the seed system (Crawford, 1997). User-oriented research for breeding consists of two main areas of work. The first area, *trait prioritisation*, precedes plant selection and aims to generate information about current, projected or potential demand to better inform breeding objectives and define product profiles. This work can make use of surveys, choice experiments and other methods. We refer to the second area as *participatory variety evaluation (PVE)*, involving variety assessment by different users, including farmers, processors and consumers. Although the term participatory variety selection (PVS) is more often used to describe participatory on-farm testing, we will refer to PVE to include testing that does not target selection. Variety evaluation can be done through on-farm trials, participatory assessment in on-station field trials or through product testing studies with processors or consumers. At different stages of the product management cycle, user-oriented research provides feedback to ensure breeding is on the right track.

User-oriented research is particularly necessary for root, tuber and banana (RTB) crops. These are often produced in heterogeneous, small-scale tropical production systems, where farmers act

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as producers, consumers and frequently also as local processors and traders (Dufour *et al.*, 2021). These activities place various demands on new varieties. However, until recently, breeding programmes often prioritised agronomic performance over other target traits valued by farmers, especially consumption-related traits and those specific to local cultures, hindering the adoption of modern varieties in tropical RTB production (Thiele *et al.*, 2020). In 2011, the CGIAR Research Program on RTB started addressing this by incorporating stakeholder perspectives more systematically in plant breeding (https://www.rtb.cgiar.org/). These efforts provide important insights for drivers of technology adoption (Thiele *et al.*, 2017).

User-oriented research provides insights about which traits are important to future users of varieties and how trait preferences differ between different user groups. Thiele *et al.*, (2020) highlight the importance of consumption-related traits and gender differences in consumer preferences for post-harvest traits as issues that influence adoption of modern RTB varieties. Other reviews have found that gender significantly influences respondents' trait preferences (Weltzien *et al.*, 2019; Marimo *et al.*, 2020). Different perspectives on traits and trade-offs may be associated with gendered roles in decision-making and involvement in different production, processing and distribution stages.

Researchers working on these issues in the Global South have made important investments in methodology and published different frameworks, methods and tools (CGIAR, 2018; de Haan *et al.*, 2019; van Etten *et al.*, 2020; Moyo *et al.*, 2021; Forsythe *et al.*, 2021). This methodological research builds on previous work by innovatively synthesising, standardising, streamlining and digitalising approaches. This renewed methodological effort is necessary to shape an improved, coherent product management process.

Ideally, user-oriented research would lead to cumulative insights regarding interactions between users and breeding products, enabling knowledge synthesis (cf. Gorman *et al.*, 2021). This places important requirements on user-oriented research. First, sampling methods should ensure that actual use contexts are represented (Kool *et al.*, 2020). Second, cumulative learning requires that gender aspects are explicitly accommodated, as this has been a limiting factor for understanding especially non-agronomic trait preferences, as indicated above (Thiele *et al.*, 2020). Third, cumulative learning can only happen if data are consistently recorded (Brown *et al.*, 2020; Gorman *et al.*, 2021), to facilitate aggregation and comparisons and ensure the data reflect dimensions relevant to user experiences with breeding products. PVE focuses on similar sets of traits as trait prioritisation, so that researchers can evaluate (1) if breeding has indeed led to varieties with improvements in the traits that farmers have given most weight and (2) whether trait prioritisation effectively predicts what farmers prefer when they are presented with actual crop varieties. Fourth, learning across time can only take place if past research datasets are published and well-documented, so that data are accessible and understandable for researchers in the future.

This study examines these four requirements for cumulative learning in user-oriented research supporting RTB breeding. We reviewed the existing unpublished and published literature for five RTB species: *Musa spp.* (bananas and plantains), *Manihot esculenta* (cassava), *Solanum tuberosum* (potato), *Ipomoea batatas* (sweetpotato) and *Dioscorea spp.* (yams). The literature search found publications that report on user-oriented research linked to breeding work on these crops over the last three decades. We created a database on these publications and recorded different characteristics for each publication, covering the four aspects indicated above (Valle, 2021;Valle *et al.*, 2022 ; Supplementary Material Table S1). A systematic meta-analysis was not feasible or desirable given that much of the relevant literature is not in peer-reviewed journals. To examine representativeness, we analysed the overall geographic coverage of the studies. On gender, we examined if studies addressed this aspect explicitly and if they did so which types of methods were used. To examine data harmonisation, we focused on a main aspect: trait definitions and inclusion in studies. Such explorations give clear indications whether the current state of the field allows for knowledge synthesis and cumulative learning.

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We describe the methodology in more detail in the 'Materials and methods' section, and our findings in the 'Results' section. We synthesise these findings and provide indications that can help to focus future efforts in the 'Discussion' section. We close with broader remarks about the remaining challenges for user-oriented research in RTB breeding.

Materials and Methods

Literature search and paper selection

The aim of the literature search was to obtain access to a reasonably comprehensive set of literature on user-oriented research related to RTB breeding. Much of the literature in this area is not published in peer-reviewed publications and is called 'grey literature'; our searches in Scopus yielded a very low number of publications. This made it difficult to follow the standards of a systematic literature review. Our aim was therefore rather to maximise the number of publications through different search strategies.

In Google Scholar, we searched with the following keywords: 'traits', 'farmer', 'participatory', 'selection', 'evaluation', 'preferences', 'assessment' and 'variety' together with the respective RTB crop names (banana, cassava, potato, sweetpotato, yam). We also searched with their equivalent translations in Spanish, Portuguese and French. Some keywords are very broad but ensured that we captured a broad set of literature and did not inadvertently exclude papers; filtering was done in the next step. Publications referenced in the identified publications were also retrieved if available online. Most pre-2000s publications could not be retrieved this way, so the literature was limited to post-2000. We received some unpublished papers and theses from researchers' personal archives and also added these to our collection. We performed our search in September 2020, so this is the cut-off point for the inclusion of publications; no publications from after this date were included.

While the publications were only selected if they involved participatory evaluations and trait prioritisation exercises, other forms of participation by processors consumers and sensory-panel evaluations were recorded in the database when they occurred in the selected publications. However, in a next step, we narrowed down the reviewed studies to those which actively included crop variety end-users in the research, focusing on trait prioritisation with farmers and participatory variety testing done with farmers (which may also involve non-agronomic aspects). Specifically, we excluded any reports on on-farm trials that collected agronomic data but did not examine farmers' perspectives or preferences regarding the tested varieties. All scholarly publications and grey literature available online were compiled, and information was extracted and entered into an MS Excel database (Table S1). This database forms the basis of this research and is made available through the Dataverse repository (Valle, 2021). Valle (2021) provides additional information about other variables extracted into the database, which are not all used for this paper.

Extracting general data: crop, geolocation, type of study, gender

First, we extracted from each study the date of publication, whether it contained open datasets, and the names of the study locations and their geographic coordinates. If coordinates were not reported, we retrieved those using online resources, including latitude.to, tageo.com, Google Maps and Open Street Maps.

Second, we recorded the crop for each study. In the database, we recorded banana and plantain separately, as well as their use type: cooking, dessert, roasting or beverage (beer and juice). In the analysis, however, it was difficult to separate them. Cooking banana and plantain are often used for the same purposes and many studies involved both plantain and banana, and various use types. Publications on banana and plantain were therefore treated as a single group: banana.

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We identified the type of study, mainly 'farmer evaluation' and 'trait prioritisation', which often are combined in one paper. For each study, we recorded information on study protocols such as the use of focus group discussion (FGD) or questionnaires, trial type and management, number of participants and sampling strategy.

Lastly, we extracted data on gender aspects of each study. In relation to gender-related effects in user-oriented research, Weltzien *et al.* (2019) indicate that the usual gender disaggregation does not necessarily lead to relevant insights. Therefore, we subdivided this into several aspects and recorded: (a) the proportion of female participants, (b) gender-sensitive sampling strategies, (c) gender-disaggregated data analysis and (d) explicit discussion of gender aspects.

Analysis of spatial and temporal coverage

We characterised the datasets in terms of the coverage across regions and time periods. Also, we determined if the geospatial coverage of the study coincided with the production areas of the different crops. This analysis was done only for sub-Saharan Africa (SSA), as this was the region that corresponded to most of the studies in the database.

To analyse temporal and broad regional trends, we grouped publications into six macro-regions: South America and the Caribbean (no publication was identified for Central America); Southern Africa; East Africa; West Africa; Central Africa and Asia and the Pacific. Papers were selected considering the inclusion in the studies of farmer evaluations and/or trait prioritisation. To analyse the temporal distribution, we grouped entries by 5-year periods based on the first year in which the trial was conducted or established. This date is more informative than the date of publication, which may have taken place sometime after trial completion. Information on the first year of trial execution was absent in 37 publications (30%), so we used the year of publication to assign a study to a period.

For the specific analysis of coverage of the production areas, we clustered location coordinates of the different studies by country and first administrative level unit using QGIS3 (QGIS Development Team 2021). To map the production areas, we used the MapSpam 2017 SSA dataset (IFPRI, 2020) since it was the only one with complete data for all relevant countries. We generated maps showing the country-level distribution of studies by methodological framework. For country-level analysis, centroids were generated based on the study coordinates.

Trait data processing and analysis

Researchers often preselect traits for studies that farmers are asked to consider in their scoring/rating or ranking of varieties. Researchers should ideally select these traits considering previous research and include those traits that are important from the perspective of farmers and other users. Knowledge synthesis requires that studies are comparable and representative in this respect. Our analysis assesses to what extent traits selected by researchers for closed questions in variety evaluations are representative of farmer priorities.

To obtain the data for this part of our study, we extracted the traits that were mentioned in the 'Results' section of the papers and noted them in the database in the original reported name as well as in a standardised form. Standardisation was done in a conservative way. This means that we grouped traits together only if they had the same meaning with no place for ambiguity or alternative meanings, or else we preserved them in their original form. The preferred trait state, for example, *tall* or *short* in the case of the trait *plant height*, was recorded if this preference could be considered to be non-universal. On the other hand, a preference for *higher* yield can often be considered universal, all other things being equal. We also placed each trait into a broader category (e.g. agronomic, morphological, quality) and linked each trait to a unique trait/variable identifier, following the CGIAR Crop Ontology (Shrestha *et al.*, 2012; Pietragalla *et al.*, 2020). Farmers' preferences could not always be related to the Crop Ontology, which tends to cater to quantitative

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protocols. To expand our functional classification, we drew on Marimo *et al.* (2020) (Supplementary Material Table S2).

From the set of studies with farmer evaluations, we retrieved the sets of traits that researchers asked farmers to consider in scoring and/or ranking varieties. For brevity, we call these ‘researcher-prioritised traits’. To generate a list of traits prioritised by farmers, we extracted traits from trait prioritisation studies that reported free-listing exercises, in which farmers expressed preferences in an open-ended way. For brevity, we call these ‘farmer-prioritised traits’.

We used R to generate matrices that represent trait frequency by publication (R Core Team, 2017). Due to the number of studies available, we could only analyse cassava and banana in a meaningful way.

For each category of traits, we calculated the number of unique traits included in that category and recorded the most frequent single trait. The average weight of each category was calculated across all publications in terms of the number of traits per category as a percentage of all traits mentioned in one publication. To assess the level of homogeneity in the traits studied, we plotted a unique-frequency matrix for all traits and publications, both farmer- and researcher-prioritised (Supplementary Material Figure S1).

Interviews

As part of the analysis, we consulted 11 experts, including 7 breeders for each crop, 1 social scientist and 3 data scientists through informal interviews to collect their vision and suggestions. We discussed the limited production of peer review papers for the studies as well as the reduced number of open datasets. They provided us with additional grey literature that we integrated into the review. The experts also indicated possible reasons for the high-density location of studies in certain regions and helped us to understand why some breeders misinterpret farmers’ traits or how the user-oriented research revealed the importance of traits that were overlooked by scientists.

Results

Spatial and temporal coverage of studies

The database contains 123 entries, of which 41 correspond to banana, 31 to cassava, 22 to sweetpotato, 16 to yam and 13 to potato. The oldest publication is from 1996 and only two publications are pre-2000s; therefore, our results describe research in the last two decades. The temporal distribution shows two cycles, the first peaking in 2005 and the other in 2015, after which publication of user-oriented research diminishes, possibly reflecting a lag in publications for the last 5-year period. Banana studies prevailed until 2010, whereas in the subsequent period cassava was the crop with most user-oriented research studies.

Figure 1 represents the spatial distribution of studies. The nature of the location data also means that our sub-national maps should be taken to offer only information about the broad trends and should not be overinterpreted. First, the level of detail provided varied greatly across publications. This also affected our analysis, as papers reporting individual village location have more location data points than publications that only indicated the total number of sites (e.g., ‘ten locations in Ogun State’). The weight of locations from a few precise papers results in a coverage density bias towards some regions. Also, first-level administrative units are of very different sizes.

Figure 1a shows that user-oriented RTB research is mainly clustered in two areas: one in West Africa, mainly Nigeria and Ghana and another in East Africa, mainly Uganda. In Latin America, Brazil and Cuba stand out although user-oriented research has been less prevalent in this region, and in Asia even fewer studies have been reported. Figure 1b and c shows the two main areas of concentration of the two major crops: banana and cassava, and trial locations of the studies at first administrative unit level. We observe that banana studies concentrate around the Great Lakes

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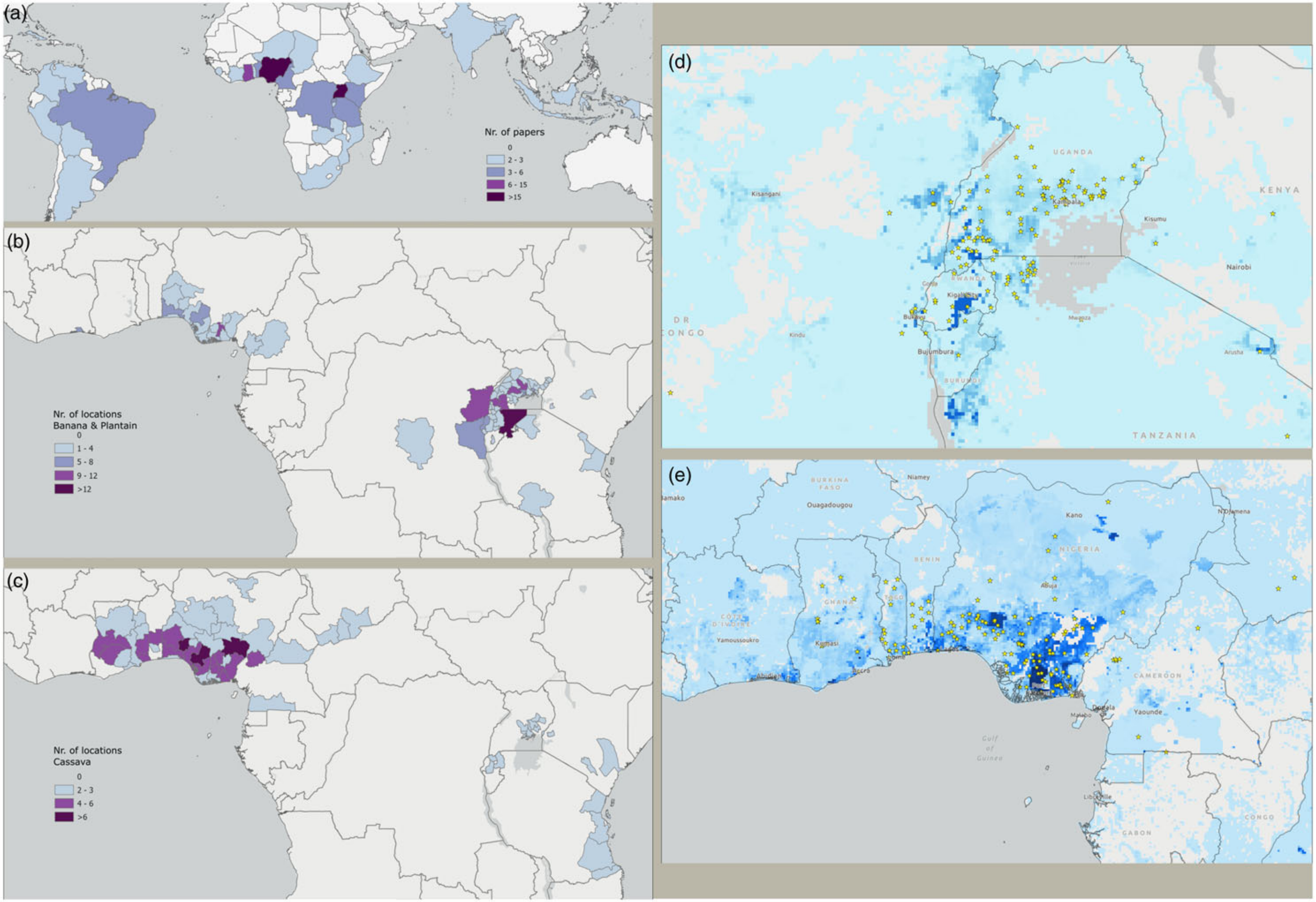

Figure 1. (a) Maps of number of RTB crop evaluation studies by country; (b) number of studies at first-level administrative units for banana/plantain; (c) number of studies at first-level administrative units for cassava; (d) study locations (yellow stars) and areas of cultivation (blue colour scale) for banana/plantain in East Africa and (e) for cassava in West Africa.

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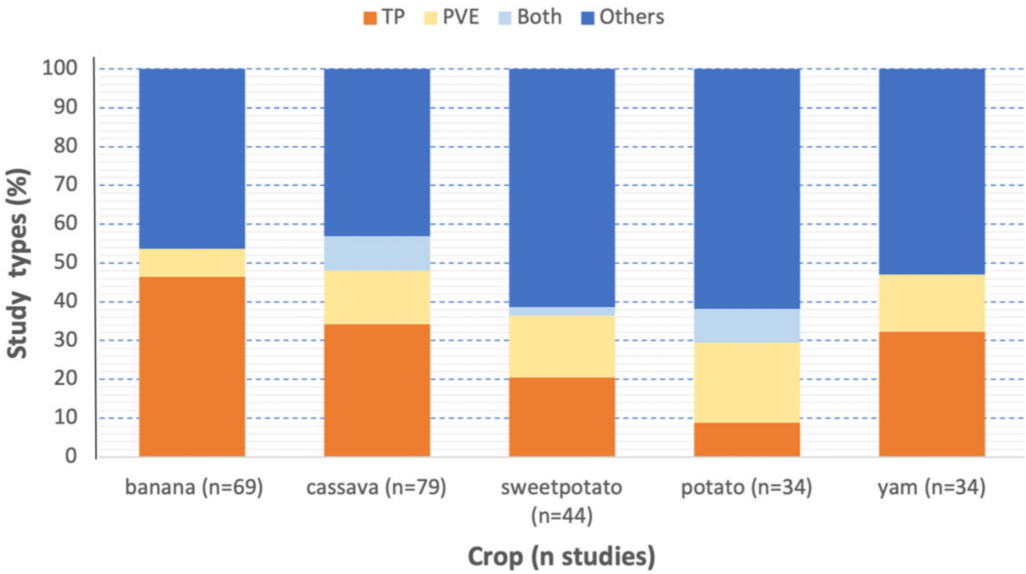

Figure 2. Percentage of study types per crop in all regions (total study types = 260). TP = trait prioritisation; PVE = participatory variety evaluation; both= TP + PVE; others = clonal evaluation, consumer tests, etc.

Region of East Africa whilst for cassava, West Africa is the centre of user-oriented research, specifically the coastal crescent along the Gulf of Benin, between Ghana and the Niger Delta.

Figure 1d and e illustrates the overlap of the sampled locations with the main areas of cultivation for cassava and banana. In the case of cassava, the area of study corresponds with the main areas of cultivation around the Gulf of Benin but lacks coverage of Northern Nigeria, Sierra Leone and Côte d'Ivoire as well as Central Africa. As for banana, studied locations are concentrated around a diagonal line extending from Kampala (Uganda) to Bukavu (DRC) passing through Mbarara (Uganda), Kagera (Tanzania) and northern Rwanda, missing main areas of cultivation further north and south.

Patterns in type of study

Trait prioritisation studies are the most frequent type of study in the review (Supplementary Material Table S3). They were reported by 60% of the overall set of publications. They have been particularly common in cassava and banana research and less common in potato, sweetpotato and yam (Figure 2). Farmer evaluations have been particularly common in potato but relatively rare in banana.

In 59% of instances, PVE exercises were performed by researchers or by farmers under supervision by researchers or using their recommended practices. In 41% of the studies, on-farm trials were managed by farmers (individually or collectively) and without recommendations from researchers.

Trait prioritisation studies have been concentrated in both East and West Africa (Figure 3), especially Nigeria and Uganda. Farmer evaluations have been more frequent in West Africa as well as in South America (mainly Brazil) and the Caribbean (mainly Cuba), yet most studies of this type were performed in East Africa, mainly in Kenya and Ethiopia. (Supplementary Material Tables S4, S5 and S6).

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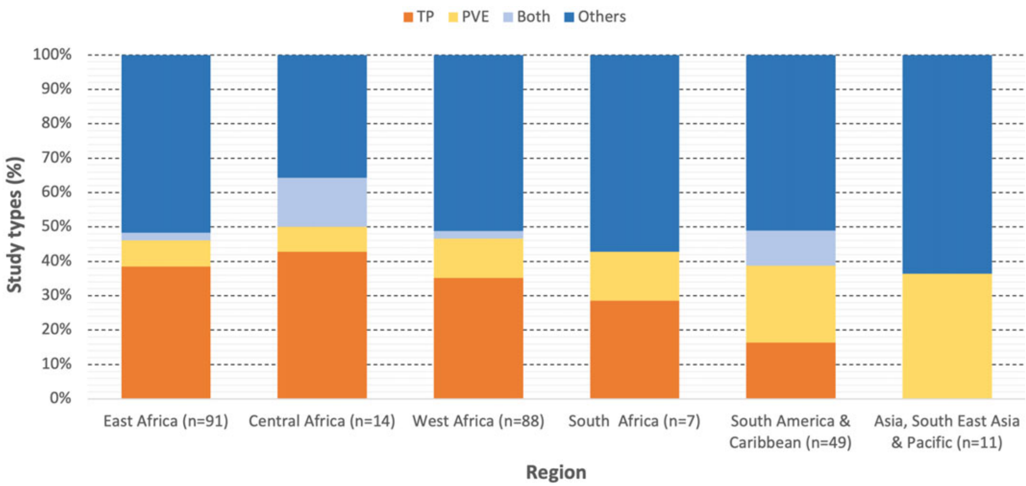

Figure 3. Percentage of study types in each region upon total types in all regions (total study types = 260). TP = trait prioritisation; PVE = participatory variety evaluation; both = TP + PVE; others = clonal evaluation, consumer tests, etc.

Gender aspects addressed by the studies

Of all publications in our database, 51% recorded the gender of the participants. Only 28% of the studies disaggregated participants by gender during data collection by conducting women's and men's FGDs or during the analysis by disaggregating responses of individuals. Yam, banana and potato have higher percentages of gender-disaggregated studies (all between 33 and 37%), whilst sweetpotato (23%) and cassava (13%) are lower. The two regions of Central and Southern Africa each show larger percentages of gender disaggregation than other regions (Supplementary Material Table S7).

The proportion of publications that perform gender disaggregation declined over the period studied, but these studies include those that just report gender as one more socio-economic variable and give it a superficial treatment. The proportion of studies that explicitly discussed gender-specific findings has increased in this same period. The latter group constitutes 19% of all publications, of which 75% was published in the last decade. These studies also paid more attention to processing-related traits. Studies that explicitly discussed gender aspects reported on average on 4.5 processing-related traits. Those studies that did not explicitly discuss gender reported on average 2.3 processing-related traits.

Across all studies, the average percentage of female participants is close to half of all participants (49%), but the standard deviation is high. We can identify a pattern with higher participation in Central and East Africa and in banana research which are also the areas and crops for which gender disaggregation is more frequent. The reduction in standard deviation over time suggests a tendency towards more gender-balanced sampling.

Trait priorities

In this section, we focus on cassava and banana/plantain research since the steps to filter traits issued from free-listing exercises by the farmer considerably reduced the number of papers for other crops (Table S3).

Most banana and cassava traits that were freely listed are mentioned only in one paper: 95 out of 126 (75%) farmer-prioritised traits, and 62 out of 99 (63%) researcher-prioritised traits. In Tables 1 and 2, we explore this in more detail by showing the frequency of traits by category. We indicated the most frequent trait per category and its frequency to show the level of

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Table 1. Banana: comparison of most frequently mentioned trait categories and traits in each category by farmers and by researchers in 37 trait prioritization studies

#	Trait category	Share of studies that include category (%)	Most frequent trait in each category	Share of the most frequent trait (%)
Farmer-prioritised traits (n = 420)				
1	Productivity	94	Bunch size	78
2	Organoleptic	94	Taste	78
3	Phenological	78	Early maturity	72
4	Abiotic stress	72	Drought tolerance	61
5	Pest and disease	72	Pest and disease tolerance	44
6	Socio-economic	67	Marketability	61
7	Planting material	56	Planting material availability	44
8	Processing	56	Uses	28
9	Management	33	Labour intensiveness	17
10	Conservation	28	Shelf life	17
11	Fruit appearance	28	Flesh colour	17
Researcher-prioritised traits (n = 96)				
1	Organoleptic	87	Taste	86
2	Productivity	80	Bunch weight	57
3	Fruit appearance	73	Peel colour, finger length, finger size	21
4	Pest and disease	67	Black leaf streak disease	21
5	Phenological	60	Early maturity	50
6	Plant morphology	47	Plant height	36
7	Abiotic stress	40	Drought tolerance, wind tolerance	21
8	Processing	40	Juice quality	14
9	Conservation	33	Shelf life	21
10	Planting material	33	Tallest sucker	14

convergence within each category (the extent to which a category is dominated by one or few traits). There is some harmonisation between studies in the sense that researchers often include the same major trait categories, which are also mentioned by farmers in free-listing exercises. Otherwise, there is a wide spread of traits for banana and cassava, which can be further appreciated in Supplementary Material Figures S2 and S3.

Banana traits

For banana, the top 5 trait categories show one difference between farmers and researchers (Table 1). Farmers include abiotic stress, especially drought frequently in their top traits but this trait is not often included by researchers as a trait to assess directly in on-farm testing. Researchers can analyse drought tolerance through yield, a trait they prioritised in most studies. A more important difference is that farmers give importance to marketability, while researchers do not include it among the most important trait categories. Marketability may be related to fruit appearance, which researchers did give much importance, but may also include other aspects.

Productivity and organoleptic categories are the most common amongst both farmer-prioritised and researcher-prioritised traits. 'Taste' is the most important organoleptic trait for both. Bunch size ranks first amongst farmer-prioritised traits, while the near-equivalent trait of bunch weight is third amongst researcher-prioritised traits. Another trait prioritised more by farmers than researchers includes early maturity (72% vs 50%). Diverse organoleptic traits are emphasised by researchers, with 'texture', colour of cooked food and flavour appearing amongst the top 10 (Figure S2). 'Fruit appearance' appears as the third most included category for researchers but is 10th for farmers. In the fruit appearance category, peel colour, finger length and finger size were the most frequently included by researchers while farmers most frequently mentioned flesh colour.

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Pest and disease incidence is almost equally important for researchers and farmers. Researchers are more specific, indicating *Mycosphaerella fijiensis* (Black Leaf Streak) tolerance as the single most-mentioned trait within this category. Plant height is the most common trait in relation to plant morphology for both researchers and farmers; however, this category did not enter the top 10 for farmers. Performance in poor soils appears as an important trait to farmers and is mentioned in over 50% of publications yet it is uncommon among researchers. Production of sufficient planting material in terms of quality and quantity is of paramount importance to farmers (56%) and although it is underpinned by multiple biological traits, it was mostly mentioned in general terms as planting material availability (44%). When it comes to researchers, the frequency of this category comes down to 33% and appears fragmented into many different traits, with no clear emphasis on traits related to planting material among breeders.

Cassava traits

As for banana, the cassava trait priorities for farmers and researchers show the same broad trend (Table 2). In the top 5 list for farmers and researchers of trait categories, there is only one category that does not occur in both lists.

A striking difference is the importance that farmers give to cassava root conservation, mainly referred to as storability in the soil, which is lacking among the top traits included by researchers to be studied in on-farm trials (Figure S3).

Fresh root yield appears as the single most common trait in both cases and the main indicator of productivity. Early maturity is the second most frequent trait amongst farmers and is mentioned in 82% of the publications; however, surprisingly it did not appear amongst the researcher-prioritised traits. Instead, the single most-mentioned phenological trait selected by researchers was height at first branching (29%).

It is also clear from Table 2 that the organoleptic traits are important to farmers (86%) and dominated by taste (63%), followed by root fibre. For researchers, the organoleptic traits appear less important overall (57%). Planting material availability is also mentioned more frequently by farmers (59%) than it is included by researchers in studies (36%).

Data publication and reporting standards

The database includes a large proportion of grey literature (PhD thesis, reports). Of all the entries in our database, 56% did not have a digital object identifier. Even though the reviewed literature was relatively recent and considering there has been an increasing trend to include raw datasets in scientific journals, only 5% of all publications included raw open-access datasets.

The sampling strategies most often recorded in the database are voluntary, random or convenience sampling, generally based on lists of members in organisations or project beneficiaries. Only 19% of all publications included coordinates and most publications omitted the exact locations for data collection or the information was limited to the number of villages within an administrative region. Local village names are often difficult to trace to a location, due to homonymity, lack of spelling standardisation or absence of geographical records; a few villages could not be located with certainty. Overall, it is possible to reconstruct the geographic location at least at the level of sub-national areas, which was sufficient for our study, but for cumulative learning in user-oriented research, it is important that data extraction can be done with less effort and more geospatial precision.

Reviewed publications did not follow a standard format in reporting. This also means that many aspects that may be important for interpretation and accumulative learning are not systematically reported. Plot management is often not explicitly described or described in general terms for the entire trial as being representative of farmer practice, but without describing variation between individual plots. The criteria used to sample participants in studies and the reasons

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Table 2. Cassava: comparison of most frequently mentioned categories and traits in each category by farmers and by researchers in 44 trait prioritization studies

#	Trait category	Number of studies that include category (%)	Most frequent trait in each category	Relative share of the most frequent trait (%)
Farmer-prioritised traits (n = 537)				
1	Productivity	100	Fresh root yield	91
2	Pest and disease	91	Pest and disease tolerance	45
3	Phenological	91	Early maturity	82
4	Organoleptic	86	Taste	63
5	Processing	86	Ease of peeling	50
6	Conservation	68	Soil storability	55
7	Plant morphology	68	Plant height	36
8	Planting material	59	Planting material availability	27
9	Abiotic stress	55	Drought tolerance	45
10	Tuber appearance	55	Flesh colour	36
11	Socio-economic	45	Marketability	41
Researcher-prioritised traits (n = 123)				
1	Productivity	93	Fresh root yield	93
2	Pest and disease	64	CMD (*Begomovirus sp.*) tolerance	43
3	Organoleptic	57	Root dry matter	50
4	Plant morphology	57	Plant height	50
5	Processing	43	Ease of peeling	14
6	Phenological	36	Height at first branching	29
7	Tuber appearance	36	Root shape	21
8	Planting material	36	Cutting production	14
9	Tuber appearance	36	Root shape	21

for these methodological choices are often not described in detail. Another area in which reporting is important is the relation between management in the experiment and under farmer conditions (Kool *et al*., 2020). Most on-farm trials were done with researcher supervision and recommendations, but the relation with farmer management is often not clear. Also, traits were recorded in ways that made it difficult to trace interpretation and translation. There was no access to verbatims or details on how original traits were grouped and classified, which would have allowed better interpretation and contextualisation.

Discussion

Spatial and temporal distribution of user-oriented research

We observed an uneven spatial distribution of user-oriented research in RTB breeding which does not clearly match the banana and cassava main production areas. From our interviews with experts, we derived various factors that influence this pattern.

The first factor is the proximity to local research institutes. For example, there is a large concentration of studies around the National Root Crops Research Institute in Umudike, Nigeria. Convenience in terms of proximity, logistical access and transportation costs is likely to explain this pattern. Second, user-oriented studies are generally focused towards areas where cassava makes a relatively large contribution to food security (SSA), which are not necessarily areas with large production, as production may be destined to industry (Thailand or Paraguay) or export (Costa Rica) (Hernan Ceballos, personal communication, September 2020). Third, the spatial pattern can be explained by international funding targeting. SSA has been the most-targeted region for all crops, which is also the region for which most international development funding is available. A fourth factor is the relative operational costs of different types of user-oriented research for different crops. The length of the crop cycle may explain the emphasis on trait prioritisation in banana (long cycle) and the emphasis on PVE in potato (short cycle). The temporal distribution, with distinct peaks in user-oriented research over time, is possibly related to trends in

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international funding. Given the moderate number of studies, a single project can have a large influence on the distribution over time and space.

Overall, the proportion between the two types of user-oriented studies, trait prioritisation and PVE, is not drastically different between regions. This means that in broad areas where one type of study is available, the other type is also available. This is positive in terms of cumulative learning, because, at least in principle, trait prioritisation can feed into breeding. The resulting genotypes can then be tested with PVE, and findings can feed into new rounds of trait prioritisation. Only in Asia and the Pacific, trait prioritisation with farmers was not evident, which can be explained from the strong focus on production for industrial use, rather than direct household consumption. At a lower level of geographic aggregation, the balance between the types of studies may vary, but our dataset is too small to draw conclusions at this level.

Relative use of trait prioritisation vs farmer evaluation

We observed that trait prioritisation studies are more frequent than farmer evaluations. One explanation for this trend is that trait prioritisation studies are cheaper and take less time to execute than PVEs. Evidence for this interpretation is that the preference for trait prioritisation studies is especially accentuated for banana, which has a long growth cycle and is difficult to reproduce at scale. The difference is smallest for potato, for which on-farm experimentation is less complicated than the other RTB crops.

Another explanation concerns the perceived relevance of each type of study to decision-making. In our informal interviews, one breeder claimed that current-format farmer evaluations often contribute little to guiding breeding objectives. This opinion is shared by others. Cobb *et al.*, (2019) suggest that farmer evaluations are not particularly efficient, as they do not address traits that are important to non-farmer stakeholders (millers, processors, consumers, etc.) and miss traits that are not visible in the field during selection. They indicate that product profiles are a preferable way forward as they are 'designed in consultation with men and women farmers, marketers, processors, and end users, distilling the requirements of all stakeholders into a blueprint for varietal development'.

This position, however, does not preclude a role for farmer evaluation in later breeding stages. Trait prioritisation and product profile generation have their own limitations and cannot elicit farmers' tacit knowledge that can only be expressed and elicited in interaction with tangible varieties. The complexity arising from trait correlations and farmer trait preferences can be context-specific and therefore best evaluated in concrete contexts. For example, early maturity in cassava is associated with poor dry-matter content and soil storability, and conversely relating to easier peeling, lower fibre content and higher yield in marginal environments (Teeken *et al.*, 2018). Preference for early or late maturity depends on how each farmer prioritises different underlying characteristics and whether their environments are marginal or not. From this example, it is clear that farmer evaluations have a complementary value to trait prioritisation exercises and provide a 'preview' of farmers' adoption decisions before variety release and seed distribution. For cumulative learning in user-oriented research, it is important that both trait prioritisation and farmer variety evaluation are done for each crop and region, so that breeding programmes can manage the product development process consistently, from user preference to breeding objectives and products, ending with on-farm performance and user acceptance of these products. As we found very different proportions of each type of study in different regions and for different crops, it is not likely that there is a healthy balance between these two types of studies.

Extent of gender-responsive user-oriented research

Our research shows a promising trend of increased attention for gender and traits associated with processing. This shows that efforts to increase awareness and understanding of gender roles in

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crop production has had some influence. Such initiatives include training courses by the GREAT programme (https://www.greatagriculture.org/) and the CGIAR RTB programme through its Gender and Breeding Initiative (http://www.rtb.cgiar.org/gender-breeding-initiative/).

At the same time, our findings show that more work on this is needed, as also found by Thiele *et al.* (2020). Few publications that record participants' gender then proceed to report gender-disaggregated results. This could be improved by adopting standard protocols. For example, simple field protocols have been developed for disaggregated participatory voting exercises (de Haan *et al.*, 2019).

On average, female participation is balanced. This is positive in itself, although it does not necessarily imply a proportional representation of the targeted end-user segment. The large variation in these proportions between studies may partially reflect researchers' responsiveness to cultural differences across locations, since in some communities, specific crops and activities are gender-specific. However, the surveyed literature does not mention prior studies on the influence of gender roles on production systems to design sampling strategies. Therefore, our results suggest that even though gender-disaggregated research has increased in the last decade, gender-related considerations are not streamlined into the research design, sampling and analysis, which still makes it challenging to gain insights in gender-related effects on user preferences. These findings confirm similar conclusions drawn by Weltzien *et al.* (2019) in their review. Teeken *et al.* (2018) provide an exemplary study on cassava trait prioritisation, showing how gender and intersectionality can be incorporated in such studies.

Coordination in trait inclusion

In broad terms, the frequency of trait categories that farmers prioritised for new varieties showed the same trends as the frequency of trait categories that researchers included in their trait lists to be evaluated. This is evidence that researchers use the results of trait prioritisation studies or other evidence on farmers' preferences when they design questionnaires for farmer evaluations. Even so, there are important differences between the farmers' and researchers' lists of traits, which we will discuss below. Another important result that invites reflection is that trait names and frequencies of inclusion vary much across farmer evaluation studies, which constrains comparisons.

There are some important traits that farmers prioritised, and researchers generally omitted. These are marketability, early maturity and drought tolerance in banana, and storability in the soil, and early maturity in cassava. Also, we have highlighted the ability to provide abundant planting materials. These differences are relative indications, as trait prioritisation studies and farmer evaluation studies did not match completely in geographical coverage. The reason that not all trait categories were included in all studies may have been that many researchers consciously chose to focus a subset of traits. For example, not all studies include yield, even though few researchers will disagree with its importance to farmers.

However, we observed a clear trend that researchers more often choose traits that are measured as biologically defined variables rather than trying to match the terms that farmers use to indicate their preferences. Farmers generally express their preferences for traits that are composites in biological terms. Marketability or taste depends on many biological factors. Researchers may intend to capture such preferences by including associated biologically defined traits. For example, researchers may approach marketability in the case of banana as fruit appearance, which is directly observable. Another example is the traits related to the provision of abundant planting materials, which was emphasised by farmers for both banana and cassava. This preference translates into several morphological traits: germination, branching, architecture, number of stems and plant height. Drought tolerance is yet another example. Farmers emphasise it as a single characteristic, but for researchers it is a complex combination of low yield and the occurrence of certain seasonal climatic conditions. Moreover, drought conditions can be defined in different ways and are not under experimental control in farmer evaluations.

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A major underlying issue here is that researchers are managing two dimensions at the same time. Farmer evaluations provide insights for variety performance in a realistic use context as well as farmer preferences. Researchers need to translate farmer preferences into biologically measurable variables to be able to make breeding decisions. Our results show that researchers tend to approach this conundrum by directly measuring these biologically defined traits in farmer evaluations. This ensures that farmer evaluations can be compared easily with breeding trials. However, it does not give additional insights into farmer preferences relative to those traits, which is one of the unique values of farmer evaluations. It precludes closing the feedback loop with the trait prioritisation studies, translating breeding progress on biologically defined traits back into progress along farmer-defined preferences, which drive variety adoption.

Focusing only on farmer preferences will not solve the issue, because this will still not allow for a translation from farmer appreciation back to crop biology. Improving translation is the key issue, which suitable methodological strategies will need to address. Combining biological measurements and farmer appreciation in farmer evaluation studies is one possible strategy. If traits are highly heritable and the evaluated set of varieties has sufficient diversity, statistical or modelling strategies can relate trait levels and farmer preferences. We have not observed such strategies in the farmer evaluation studies we have reviewed here.

The second issue that we address is the wide divergence between studies in trait inclusion and definition. The translation between different studies requires that they (1) clearly define traits and link them to underlying protocols and (2) share the same traits so that the studies are comparable, at least for a minimum set of traits. These conditions were not met for most of the studies. Researcher-prioritised traits are not standardised across studies, resulting in great variability, which precludes comparisons across time and space. Generally, trial documentation does not precisely define traits or how questions were posed to farmers. This can lead to confusion. For instance, the Crop Ontology defines poundability as related to texture: 'mealiness of boiled cassava storage root rating' (Trait ID: CO_334:0000437). In contrast, other studies refer to poundability as non-toxicity (non-bitter, low cyanogen content), sweet varieties (Bentley *et al.*, 2017; Nweke, 2004, p. 103). Therefore, explicit definitions of traits, linked to measurement methods, are necessary.

Publishing user-oriented research

User-oriented research on RTB crops is predominantly published as grey literature. This shows that there are important barriers to peer-reviewed publication of results. In our interviews, it became clear that much research even remains unpublished (Elisa Salas, personal communication, August 2020). One important barrier mentioned in the interviews is that scientific journals require some degree of novelty in terms of methods or approaches, as the findings themselves are often not found to be of sufficient value for publication. This stands in the way of creating an environment in which accumulative learning can happen, as it becomes more difficult for researchers to compare results across time and geographical space. As this rarely happens, the trend may be self-reinforcing: data are not published due to the perception of limited value, and not used because it remains inaccessible.

To counter this trend, a data culture needs to be fostered, which encompasses various aspects. Technical barriers are not insurmountable. In principle, it is already possible to publish datasets for free in public repositories, such as Dataverse (https://dataverse.org/) or Zenodo (https://zenodo.org/). Dataset documentation can be published as part of the dataset and in so-called data journals (e.g. *Data in Brief, Scientific Data*). Novelty is not required for publication in data journals. However, researchers and journal editors may have low expectations regarding the benefits and possibilities of using crop trial data beyond the immediate decisions that trials are supposed to inform.

Therefore, it is important that analyses using on-farm trial data become more prominent. Data synthesis of crop trial results can provide important new insights in variety performance across

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geographical space or to detect genetic gain, a measure of breeding progress over time. In principle, data synthesis can be applied to heterogeneous on-farm crop trial data, which could already spark interest in data sharing for such analyses with extant data, hopefully starting a virtuous cycle of data sharing (Brown *et al*., 2020).

As such data synthesis efforts develop, it would be clearer to researchers that data standardisation would provide even more possibilities for data synthesis. Electronic field books for on-farm testing could implement standardised forms that link each variable to ontologies and standardised formats, such as the Crop Ontology (https://www.cropontology.org; Arnaud *et al*., 2020) and, for socio-economic data, Rural Household Multi-Indicator Survey (Hammond *et al*., 2017) and the G+ tools for gender-responsive breeding product management (Ashby and Polar 2021). Data publication should adhere to data standards, such as the Findable, Accessible, Interoperable and Reusable (FAIR) standards (Wilkinson *et al*., 2016). Data publication standards for on-farm trials could help to set new expectations in this area of research.

The various requirements may be bewildering for researchers. Training is necessary to learn about them. However, at the same time digital tools can help to make tasks easier. New digital tools can integrate different aspects (standardisation, analytics and data publication) in a streamlined way and facilitate experimental design, drastically reduce data cleaning needs and give access to advanced analytical procedures. Digital tools do not only enable the implementation of these aspects but can be more efficient and user-friendly than current paper-based alternatives. In having access to high-quality digital tools, researchers will have stronger incentives to become part of a new data culture.

Synthesis of findings

In the period examined here, a substantial volume of user-oriented research has been done on RTB crops. In this study, we examine if the way in which these studies are executed allows for cumulative learning. Although breeding product management requires both trait prioritisation and PVS, we found that many crops and regions have a strong tendency to report much more of one type than of another type of study. We interpret this as an indication that the field is still at an early stage in its progress towards an integrated use of user-oriented research for breeding product management.

On the methodological front, we also found that studies have increasingly become gender-sensitive but generally address this aspect in a limited way. Second, we found that traits included by trait prioritisation and PVS do not facilitate the linking of social and biophysical dimensions, which makes it difficult to translate user preferences into breeding selection strategies. From a methodological point of view, much could be gained from further reflection by groups of experts, working on common guidelines and protocols to improve user-oriented research methodologies.

We also found that limitations in publication of user-oriented studies and datasets hamper cumulative learning. A data culture requires access to high-quality digital tools and training, as well as clear examples of the ensuing benefits of data sharing and synthesis. Building a data culture requires a consistent, broad investment in tool development, training and continuing dialogue among professionals. Investors and decision-makers need to foster experimentation with innovative, data-driven research across disciplines. They need to drive the most successful innovations to be combined into integrative tools and standardised procedures in product management cycles so that user-oriented research can enable cumulative learning in demand-led breeding and enhance variety adoption.

Supplementary material. For supplementary material for this article, please visit https://doi.org/10.1017/S0014479722000539

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