Research Article

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Varietal diversity as a lever for cassava variety development: exploring varietal complementarities in Cameroon

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Abstract

BACKGROUND: Cassava is an important crop for the survival of smallholder farmers in Cameroon. However, the cassava sector has a low production per unit area compared to the technological potential in this country. In this context, breeders have developed varieties based mainly on their potential in terms of yield and disease resistance. These varieties have been widely disseminated in Cameroon within the framework of development projects. However, these releases have not achieved the expected adoption and yield levels at the national level. Therefore, it appears important to rethink the determinants of dissemination with a broader examination of the cassava production system.

RESULTS: This paper analyses varietal complementarity as a key strategy in support of optimizing the experimental and continuous use of cassava varieties by farmers in the Central and Eastern regions of Cameroon. These two regions account for 50% of the country's production. A total of 111 semi-structured interviews were conducted with farmers selected through purposive sampling in four villages in Central and Eastern Cameroon where improved varieties have been disseminated. The research revealed four types of complementarity, related to use, crop management, risk management and cultural complementarity.

CONCLUSION: Our results argue for considering varietal complementarities practiced by farmers, within research and development programs to develop more effective breeding and dissemination approaches.

Keywords: varietal improvement; adoption process; dissemination strategies; breeding

INTRODUCTION

In Africa, cassava contributes to food security, generates income for rural populations[1-3] and helps reduce wheat flour importation, a major source of monetary outflow.[4] Cassava's strategic position is due to its multiple uses, its flexibility in harvesting time and its resistance to extreme conditions.[5-7] This study focused on Cameroon, which is among the most important producers in Africa. To date, the yield and competitiveness of cassava are threatened by climate change, diseases, pests and declining soil fertility.[2] In response, development programs have bred and disseminated new varieties.[8] Although these varieties have the potential to overcome environmental and production-related risks,[2,9] they do not always meet the needs of producers and consumers, especially related to the organoleptic properties such as texture and palatability of derived food products.[10] Consequently, new approaches aim to systematically integrate the needs along the value chain.[11,12] Cassava breeding must not only focus on high and stable yields (producer-related) but also include other needs from processors, marketers and consumers[13] and take into

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account that women often dominate in production and processing work.[11,14]

There is still a low adoption of bred varieties, which is reflected in the high level of preservation of local varieties (also referred to as landraces).[15] Indeed, contrary to research projections, the diffusion of new varieties often does not lead to a major replacement of landraces by new ones.[6,10,16] Rather, when adopted, new or improved varieties are combined with landraces.[6,17] This association is driven by the role assigned by the producer to each variety and the fundamental role of cassava in food security. In all sub-Saharan Africa, including Cameroon, family farming is dominant. For the latter, new varieties may be a means of increasing yield, but also (and sometimes more importantly) a means of subsistence, cultural satisfaction and a strategy for spreading risks.[6] Thus, we hypothesize that the use of new varieties is a decision to experiment, and then possibly to add to those already cultivated. This decision is most probably not based on a calculation or logic directly related only, or even mainly, to the yield gain, but may be more contingent on the capacity to complement the landraces in addressing the various needs that are determined by the social, cultural and economic context of the crop users.[18]

Following their addressing of the problem of adoption and other so-called linear classical approaches,[19] Glover *et al.*[20] propose to analyze the innovation process through four features, proposition, encounters, dispositions and responses, to do better justice to its nature. Here an innovation is defined as an outcome: the way the introduced technology produces a useful result for the user. This result might be different from the one aimed at by those who developed the technology. The concept of proposition refers to the different possibilities of perceiving an innovation as an opportunity and refers to the idea of how the technology is to address a certain constraint, produce a certain outcome and is thus the intention behind the technology development: how the technology is to create innovation. A technology therefore often has a biophysical material component and a set of guidelines, assumptions and instructions. Encounters highlight the opportunities where potential users can become aware of the propositions, while dispositions highlight the unique orientations of each of the potential technology users: the way in which the proposed technology is perceived as a relevant and thus an interesting opportunity. The concept of responses highlights the multitude of broad and diversified reactions and/or engagements with the proposed technology (proposition). These responses are often hidden by the dichotomous nature of the concept of adoption. Among the multitude of responses are experimental use and continuous use.[21] According to Takam,[22] experimental use is the commitment of a producer to evaluate a technology to which that producer has been exposed, and continuous use refers to the reaction of a producer who uses a technology no longer with the aim of evaluating it, but because he or she has become satisfied with it: the technology now has a certain function for the user and has become an innovation from the perspective of the user. It has to be stated that the four concepts are interrelated causally and linked by feedback loops. Therefore 'experimentation with the technology', although a response by the user, can also be conceptualized as 'disposition' as it contributes to shaping the unique way of the orientation of the user determining the user's final response, using the technology or not. As stated, the final function that the technology serves might be very different from the one assumed behind the development of the technology.

This study therefore focuses not only on the part of the process of varietal innovation related to farmers' experimental use of new varieties but also on a holistic view of continuous use of the varieties,[21,23] including consideration of the environment (ecological and social) in which production takes place.[24,25] To understand the forms of complementarity among varieties, we analyzed multiple criteria that farmers use in their characterization of cassava varieties and their production systems, as well as their process of moving from experimental to continuous use of a new variety, when varieties really become an innovation that addresses a certain function that serves the user. The objective of this study is thus to investigate the relevance of different forms of varietal complementarities for varietal development and dissemination.

Literature shows that the adoption of new varieties often contributes to a farm diversification strategy aimed at meeting specific, contextual needs.[26] Farmers acquire varieties that can each fulfil one or more specific functions related to their needs. These functions may be linked to several criteria, including the management of production risks[27] and the satisfaction of quality criteria.[12,14]

Producers in Cameroon rely on cassava varietal characteristics such as type (bitter and sweet),[28,29] cassava production cycle (short and long)[30] and the identity of the plant material (improved variety and local variety).[2] Improved varieties are often preferred for making processed products (starch, *gari* and *bâton de manioc*), while sweet landraces are preferred for direct (boiled) consumption.[2,10]

Knowing that a single variety cannot fulfil all functions on its own,[2] farmers in Cameroon are therefore hypothesized to combine several varieties, following their criteria, in search of one or more functions. This is considered as varietal complementarity, which is the main subject of the present study.

MATERIALS AND METHODS

Study area

The study was conducted in two villages in Central (Minkoa and Mbanga) and two in Eastern (Djenassoumé and Zoguela) regions of Cameroon. The two regions account for nearly 50% of national cassava production.[31] The villages were selected because they had been exposed to improved varieties through a widespread distribution of planting material by a research and extension program over the past 15 years (National Root and Tuber Development Programme, NRTDP).[32] The four were selected from about 50 villages per region in which the NRTDP worked. The choice of these villages, made with the help of former NRTDP managers, was based on the level of adoption of the improved varieties. In each region, adoption in one village was lower (Mbanga and Zoguela), while in the other, adoption was higher (Minkoa and Djenassoumé). The careful selection of locations guaranteed that farmers were as familiar with the improved varieties as they were with their landraces, that planting material for both type of clones was available and that farmers had sufficient opportunity to test and use the improved varieties.

Data collection

Data were collected using a semi-structured interview guide, from farmers who had been growing cassava for at least two years. A total of 111 farmers were randomly selected and interviewed in Djenassoumé (29), Zoguela (30), Mbanga (27) and Minkoa (25) between 4 May and 4 June 2021. The interview guide was used to obtain data on the varieties grown by producers in the zones, the characteristics of the cropping system in which cassava was grown in the target zones and the reasons that motivated producers to choose and maintain such a system. It was administered for an average of 2 h.

Data analysis

The data collected were analyzed in two ways. In the first case, descriptive statistical analyses were carried out using MS Excel 2006. Secondly, we applied thematic coding to the qualitative data. The open-ended questions from the interview guide were the basis for the column headings of the coding matrix, while each response to the questions was coded in a row. For example, responses to the questions (i) *What varieties do you currently grow in each field?* and (ii) *What type of cassava variety do you grow in each field?* were coded under *Cropping system and varietal diversity*. The answers to the questions (i) *Would you be willing to use only one cassava variety in your fields?*; (ii) *What are your general reasons for using your varieties?*; and (iii) *What is the main purpose of your cassava production?* were coded as *Functional approach*. Finally, the questions *Why did you decide to have several varieties?* and *What are the characteristics and advantages for which you initially chose to try/obtain each of the varieties you use?* were coded as *Complementarity to experimental use*.

The questions *Why do you continue to grow these varieties?* and *If no or yes, what are your reasons?* were coded as *Complementarity during the continuous use*. The forms of complementarity were deduced by manually analyzing each of the answers to these two questions for each producer surveyed. The transition between forms of complementarity at experimental use and those at continuous use was analyzed based on the comparison of the answers to the questions that were classified as *complementarity for experimental use* and as *complementarity in continuous use*. The qualitative data were coded for textual analysis according to the procedures described by Bengtsson.[33]

RESULTS

Characterization of cassava producers

Table 1 presents the socio-economic characteristics of the producers surveyed. Most cassava farmers in our sample were in the 36–50 age group, with an average of 5–10 children. Most of these farmers were women (89%). This reflected well the situation in the villages where cassava is mostly grown and processed by women, while men are more involved in perennial crops like cocoa.

Table 2 presents the distribution of producer groups by village according to three types of involvement in other cassava value chain activities: (i) producer–consumers where the largest proportion of production is for household consumption; (ii) producer–traders who reserve the largest proportion of production for sale of cassava as fresh roots; and (iii) producer–processors–traders where the largest proportion of cassava production is for sale in processed form.

In the four villages, most producers market the majority of their production. However, depending on the area, the form in which producers sell cassava differs. In the villages in the Eastern region (Djenassoumé and Zoguela), producers preferred selling cassava as fresh roots (73% and 80%, respectively), while in the Central region (Minkoa and Mbanga) farmers preferred marketing cassava in processed form (48.0% and 48.1%, respectively). Furthermore, the food product into which producers prefer to process their cassava depends on the village: in Mbanga producers prefer to make *water fufu* (paste obtained by soaking cassava roots in water for a long time (3 days)) and *couscous* (flour obtained after milling dried cassava roots), while in Minkoa producers prefer to process cassava in the form of *bâton de manioc* (cassava that is soaked (3–4 days), then crushed, sieved and wrapped in leaf in the form of a stick before being cooked).

Criteria for characterizing cassava varieties by producers

The producers surveyed base the identification of their varieties on three major criteria: type, production cycle and identity of the plant material (or group).

In the four villages, farmers classified the identity of the plant material into two groups: so-called *local* varieties (landraces) and so-called *improved* or bred varieties. The improved varieties had the particularity of offering high yields and being more resistant to diseases. They were introduced into the different villages studied mainly by the NRTDP and secondarily through other development and/or research programs, or informally by farmers. Landraces were those inherited from farmers' parents and ancestors and are therefore mainly disseminated by producers and their peers. Producers also classify varieties according to their high or low cyanogenic potential (which they equate with *taste*) into two types: *sweet* and *bitter*. Sweet varieties are those that can be consumed directly in raw or boiled form, while bitter varieties require processing into various products before being consumed because of the relatively high cyanogenic potential and/or their incapacity of softening when cooked. Finally, farmers also classified varieties according to their cycle: long cycle (when cassava roots are generally harvested from 12 months after planting (MAP) onwards) or short cycle (harvested before 12 MAP). Table 3 presents the distribution of varieties used in the four villages according to producer characterization criteria.

Table 3 shows that Djenassoumé and Zoguela had only sweet varieties. However, the varieties that abound in these villages are characterized as: landraces, sweet and long cycle. Improved varieties are in greater number in Minkoa producers' farms because of the presence of a cooperative that prefers these varieties and buys them to process into different products for sale.

Cropping system based on varietal diversity

The cropping system in the different villages surveyed is marked on the one hand by the association and rotation of cassava with several other crops such as plantain, macabo (Cocoyam: *Xanthosoma sagittifolium*), groundnuts, yams, maize; and, on the other hand, by the combination of different varieties. It is on this last aspect that this study focused.

In general, between two and eleven varieties were combined by producers according to the three criteria mentioned above. Depending on the varietal identity, three types of varietal combinations could be distinguished: combinations of several local varieties, combinations of local and improved varieties and combinations of several improved varieties. Figure 1 shows the distribution of producers according to the type of combinations linked to varietal identity by village.

While all four villages have been exposed to the dissemination of improved varieties through the NRTDP over the past 15 years, the combination of landraces was most common in three out of four villages (92% in Mbanga, 83% in Djenassoumé and 90% in Zoguela) while the combination of local and improved was most common in Minkoa (80%).

Table 1. Socio-economic characteristics of the producers surveyed

	Djenassoumé (*N* = 29)		Zoguela (*N* = 30)		Minkoa (*N* = 25)		Mbanga (*N* = 27)		Total (*N* = 111)	
Variables	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Sex										
Woman	19	65.5	24	80.0	21	84.0	25	92.6	89	80.2
Men	10	34.5	6	20.0	4	16.0	2	7.4	22	19.8
Age										
[20–35]	5	17.2	9	30.0	1	4.0	2	7.4	17	15.3
[36–49]	17	58.6	15	50.0	6	24.0	9	33.3	47	42.3
[50–65]	6	20.7	2	6.7	14	56.0	12	44.4	34	30.6
≥66	1	3.4	4	13.3	4	16.0	4	14.8	13	11.7
Household size										
[1–4]	12	41.4	15	50.0	8	32.0	8	29.6	43	38.7
[5–9]	16	55.2	14	46.7	11	44.0	9	33.3	50	45.0
≥10	1	3.4	1	3.3	6	24.0	10	37.0	18	16.2
Experience in cassava production (years)										
[1–5]	4	13.8	2	6.7	—	—	1	3.7	7	6.3
[6–10]	6	20.7	6	20.0	5	20.0	4	14.8	21	18.9
[11–20]	5	17.2	5	16.7	3	12.0	4	14.8	17	15.3
≥20	14	48.3	17	56.7	17	68.0	18	66.7	66	59.5
Size of cassava farms (ha)										
[0–1]	8	27.6	2	7.0	10	40.0	15	55.6	35	31.5
[2–3]	20	69.0	25	83.3	14	56.0	11	40.7	70	63.1
≥4	1	3.4	3	10.0	1	4.0	1	3.7	6	5.4

N, number; % of Variable × Village subset total.

Table 2. Profile of producers according to their involvement in the cassava value chain activities

	Djenassoumé		Zoguela		Minkoa		Mbanga		Total	
Status of producer	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Producer–consumer	3	10.0	3	10.0	9	36.0	11	40.7	26	23.4
Producer–trader	21	73.0	24	80.0	4	16.0	3	11.1	52	46.8
Producer–processor–trader	5	17.0	3	10.0	12	48.0	13	48.1	33	29.7

Table 3. Distribution of varieties according to characterization criteria given by producers

		Relative frequency by village (%)			
Variety characterization criteria		Djenassoumé	Zoguela	Minkoa	Mbanga
Identity of plant material	Improved variety	17	12	35	9
	Local variety	83	88	65	91
Type of variety	Sweet variety	100	100	95	77
	Bitter variety	0	0	5	23
Length of crop cycle	Long-cycle variety	75	50	95	77
	Short-cycle variety	17	50	5	23

Producers generally made two types of combinations: between sweet varieties (S–S) and between sweet and bitter varieties (S–B). Depending on the length of the production cycle, they made combinations between long-cycle varieties (L–L) and between long- and short-cycle varieties (L–Sh). Table 4 presents the distribution of producers according to the type of variety combination linked to length of the production cycle, by village.

Table 4 shows that in Mbanga, producers preferred combining the S–B type (96%), while in Minkoa, Djenassoumé and Zoguela, the emphasis was on the S–S types (72%, 100% and 100%,

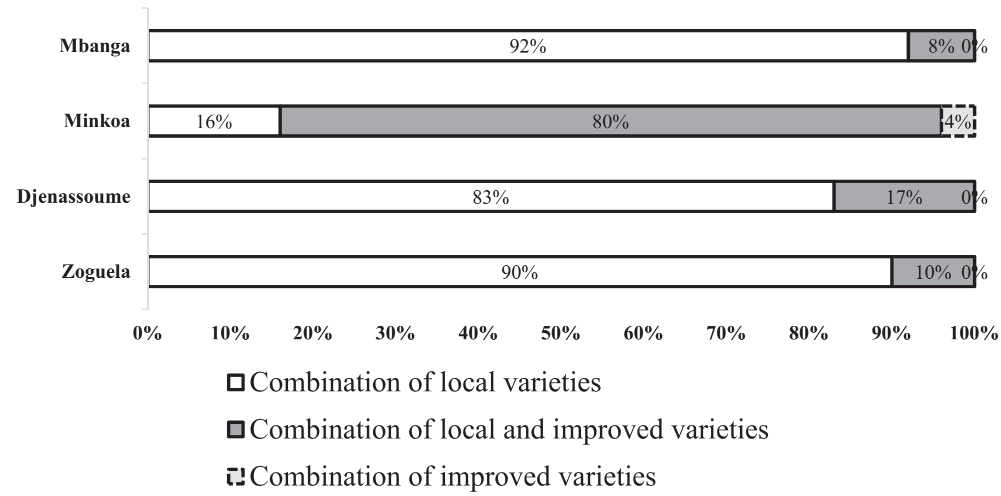

Figure 1. Distribution of producers, by village, according to the identity and combination of cassava varieties.

Table 4. Distribution of producers according to type of combination linked to type of variety and length of production cycle per village

Type of combination, depending on:		Relative frequency by village (%) Djenassoumé	Zoguela	Minkoa	Mbanga
Variety type	Sweet–sweet	100	100	72	4
	Sweet–bitter	0	0	28	96
Production cycle	Long–short	17	97	52	78
	Long–long	83	13	48	22

respectively). Farmers combined to a greater extent the L–Sh types in all villages, except in Djenassoumé.

The cassava production system in the four villages was therefore marked by a high degree of varietal diversity and it was important to know how the use of variety combinations related to the production system in these different villages.

Varietal diversity: a functional approach

Most cassava farmers interviewed were very keen on combining several varieties. Indeed, 72% said they would never use just one variety.

This varietal diversity was important to producers. They generally decided to acquire and use varieties if they see in them the possibility of satisfying some of their needs in terms of *functions*. Three main functions emerged from the analysis of the interviews: 1, production; 2, end-use; 3, cultural.

The *production function* is the ability of one or more varieties to contribute to (i) limiting production risks and/or (ii) allowing continuous availability of cassava throughout the year.

The *end-use function* refers to the possibility for one or more varieties to offer good-quality processed products appreciated by final consumers (at family level or at market level). The farmer was thus looking for a cassava variety that will meet specific use criteria, for example:

- a good table (boiled) cassava that must be soft when cooked, not bitter and very often free of woody fibers;
- *baton* with a very stretchable and white texture;
- a stretchable and white *couscous*;
- an *ndengue* (a mixture of plantain and manioc cooked and ground in a pestle) that is stretchable without a sour and/or bitter taste.

Satisfying the *cultural function* can be understood by producers preserving the landraces used by their ancestors in order to transmit them to their descendants. This tradition often includes specific values of culinary, ecological, aesthetic and social quality.[6,34] This cultural function also helps maintain biodiversity as part of a long-term strategy for spreading risk and allowing emerging discoveries/innovations.[34,35] These emerging discoveries are an important driver in the transition from experimental to continuous use, to be described in more detail under results.

Varietal complementarity as a strategy for acquiring and using varieties

Depending on the reasons for the combinations of variety types mentioned by the producers, four forms of complementarity emerged:

(i) *Complementarity of use* refers to the combination of two or more varieties to satisfy the preferences of the final consumer for the end-use function, whether the root is in fresh root form or processed. In Mbanga, for example, bitter varieties are valued for their ability to meet the quality requirements for *couscous* and *bâton*. Also, in Minkoa, a male producer said that he grew several varieties of cassava because they all had different *tastes*. For him, this diversity provided a wide range of possibilities in terms of taste and, also, a specific variety (*95*) was kept for making *bâton*.

(ii) *Complementarity linked to risk management*, which translates into the combination of two or more varieties to manage the risks (pedoclimatic and phytopathological) linked to farming. This type of combination makes it possible to fulfil the first varietal diversity – production function. As a female farmer in Minkoa said, by putting several varieties of cassava in the field, *I have the assurance that if one variety does not produce, the other will*. Indeed, in this village (as in the other three), cassava is highly exposed to root rot (72% of producers cited it as one of the main difficulties in their production). To reduce their vulnerability to this issue, farmers combine several varieties in their fields in the hope that if one variety rots too much, the others will be able to provide.

(iii) *Complementarity related to harvest management* refers to the combination of two or more varieties to ensure continuity in the production throughout the year. To achieve this, farmers combine long-cycle and short-cycle varieties. This combination favors staggered harvests to ensure the availability of roots. The early bulking plants can provide acceptable yield already at six months, followed by the long-cycle varieties at twelve months or more. This type of combination fulfils the second aspect of the production function as described above – end-use function. Harvest management through crop cycle length is very common among farmers in the villages of Djenassoumé and Zoguela. In Djenassoumé, a farmer said that she acquired the six-month variety because it produces quickly to make the cassava available at six months, while her other varieties will produce at between 12 and 15 months. This allows her *to always have cassava in the field*.

(iv) *Cultural complementarity* reflects the attachment of farmers to varieties. This attachment may be due either to tradition, i.e. it is a variety that is passed on from parents to children, or to producers' sensitivity to varietal diversity, which gives them a certain satisfaction or sense of stability. It is in this sense that a producer from the village of Mbanga stated that he uses his varieties because: …*it is also to maintain the tradition; my mother used to use them too, the habit*… With regard to a sense of stability, a producer from Djenassoumé said: *At the moment I have all the varieties because I like to have all this*. In general, this form of complementarity reveals the producer's desire to satisfy the cultural function. The percentages of different forms of complementarity in the experimental use and continuous use of varieties in the different villages are presented in Figs 2 and 3, respectively.

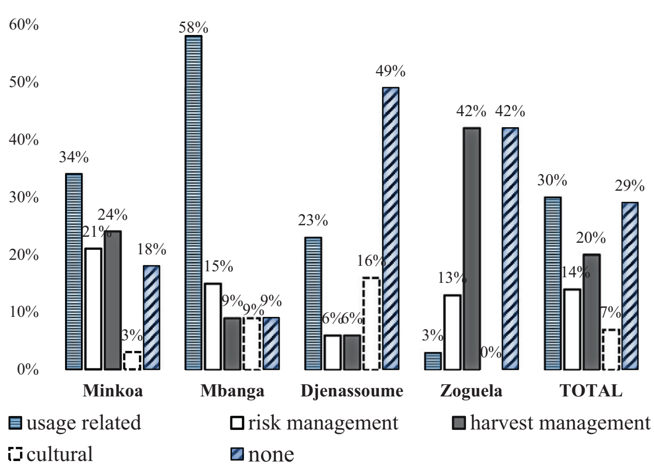

Figure 2. Comparison among villages for forms of complementarity cited by farmers in relation to experimental use of cassava varieties. *Y*-axis represents percentage of farmers interviewed who cited a form of complementarity.

A comparison of Figs 2 and 3 shows that, in general, the experimental use and continuous use of certain varieties by farmers were based on complementarity of varieties for different uses. Only producers in Zoguela were largely motivated by complementarity related to crop harvest management when acquiring (42%) and using (57%) several varieties.

To satisfy their needs, farmers generally combined varieties that are complementary at several levels; that is, several forms of complementarity were mobilized. In Minkoa, for example, a female producer states that she owns her varieties because: *The variety 'Fonctionnaire' produces quickly and so we can eat it more quickly than 8061; Mekouga is special for making a good* bâton. *It is also to maintain the tradition; my mother used it, so me too. So, it is the habit, and above all it has never disappointed me*. The choice to keep her varieties was based on the farmer having the complementary functions being met, linked to risk management, harvest management, end use and culture.

Transition from experimental use to continuous use

In general, the transition from the stage of acquisition for experimental use to that of continuous use (Figs 2 and 3) is marked by the difference in importance of each of the forms of complementarity, mainly characterized by the general reduction of the *none* category from 29% to 13% from experimental use to continuous use. This can be explained by the fact that many producers did not rely on any form of varietal complementarity to acquire their varieties. With time, they discovered beneficial functions that justified continuous use of these varieties.

When farmers moving from the experimental use phase to the continuous use phase are considered, the reasons given by the farmers may change or not. When they changed, three phenomena could occur: the addition of a form of complementarity; the removal of a form of complementarity; and/or the radical modification of a form of complementarity. Changes result from farmers' experimentation with the acquired varieties. After experimentation, producers can perceive the new varieties as

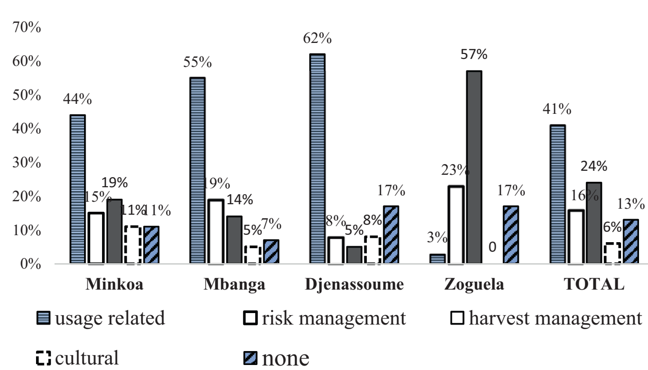

Figure 3. Comparison among villages for forms of complementarity cited by farmers in relation to continuous use of cassava varieties. *Y*-axis represents percentage of farmers interviewed who cited a form of complementarity.

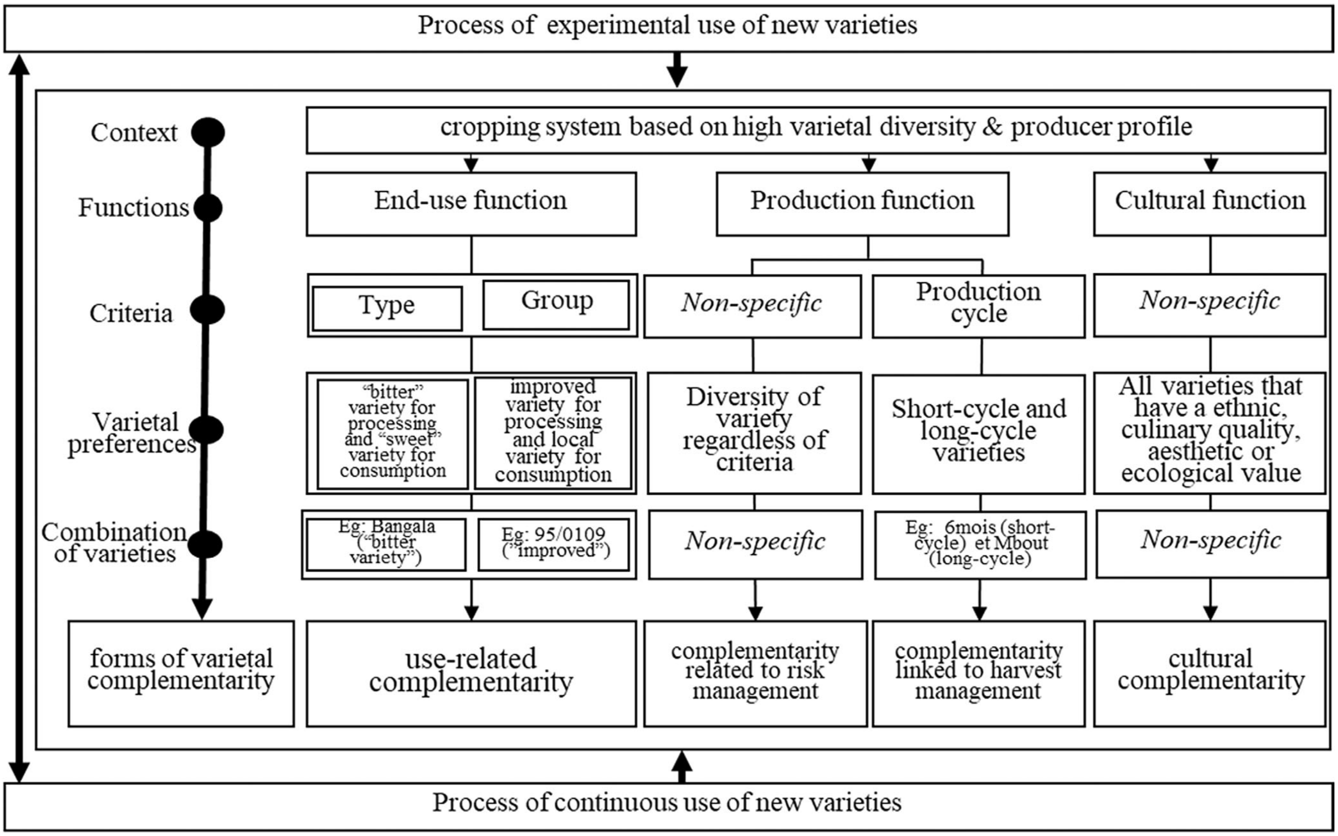

Figure 4. Components determining the strategy of complementarity for the experimental use and continuous use of new varieties.

either advantageous or disadvantageous in relation to their expectations.

Comprehensive approach to understanding the strategy of experimental use and/or continuous use of new varieties

In the four villages, cropping systems were based on a varietal diversity and by production oriented towards consumption, marketing or processing (context). The experimental and continuous use of new varieties was based on the need for producers to fulfil one or more functions related to their needs. They relied on combining variety-specific characteristics to meet their preferences, leading to various forms of complementarity (Fig. 4).

Figure 4 illustrates how producers constitute their complementarity strategies during the experimental use and continuous use of new cassava varieties. In a context dominated by varietal diversity, they are oriented towards functions that are important to them and that they seek to satisfy based on criteria strongly linked to their preferences. This implies certain combinations between varieties. The concept is the same for both experimental and continuous use, only that farmers might not be able yet to classify the varieties for experimental use as they can for continuous use as it will become more explicit during experimentation which functions varieties can fulfil for them. So, in cases where farmers are informed in more detail beforehand (as a result of the inclusion of complementarity within variety development and dissemination we propose) about the possible functions of each variety, adoption of varieties can become much more efficient.

DISCUSSION

The adoption of new technologies in agriculture is a complex phenomenon. However, in a simplified view, adoption is a binary variable (adopter and non-adopter), with transfer to replace an old technology with a new one.[19] This is a decision to make (or not) full use of an innovation as the best possible course of action.[36] This conception of adoption has been criticized by recent literature, highlighting the need to consider the dynamic relationship between farmers and their context, which co-evolve and adapt to each other[18,21,37,38] and the diversity of producer responses which include experimental[21] and continuous use[23] of technologies.

The concept of complementarity in technological innovation was first used by Milgrom and Roberts[39] to explain the revolution in manufacturing industries achieved by the adoption of technologically advanced machines and new forms of organization. The authors argue that several new technologies are adopted in a strategic manner, taking into account their complementarity to optimize a company's strategy. In this respect, Gómez and Vargas[40] argue that certain technologies should not be analyzed in isolation, as the adoption of a given technology is best explained by considering that it is part of a system with other technologies.

Several earlier studies, especially in management science, have provided evidence of the existence of complementarity between different technologies[41–43] and its positive effect on the adoption of these technologies.[40,44] However, few studies show the existence of complementarity in the adoption of agricultural technologies. Yet complementarity is an interesting approach to explain technology adoption in agriculture.[45,46]

Results of this study highlight the need for breeders to adjust their selection criteria and align them with crop consumers' preferences and farmers' varietal adoption strategies. This is consistent with the new paradigm of demand-led (e.g. https://www.demandledbreeding.org/) and transdisciplinary informed breeding.[10] Reconsidering selection criteria is crucial, as they are linked to final acceptance and important to ensure that improved varieties will be used by the people (customer or market segment) for whom they were designed.[47]

To date, the main selection criteria for cassava have been high yield, resistance to diseases and pests, high root dry matter content and low cyanogenic potential, with an emphasis on yield.[2] Our results describe the process of farmers' varietal adoption strategies and highlights that, in our study area in the Central and Eastern regions of Cameroon, producers' main priority is not to increase root yield but to optimize the complementarity of the set of different varieties they work with to serve their different needs. In these regions, subsistence agriculture practiced on small farms dominates, and where the produce is marketed as different products in a staggered manner throughout the year.

Our study showed that in choosing new varieties, farmers consider aspects such as: length of the production cycle (to manage harvests and spread them across the year); ability to produce different and good-quality food products (fresh roots in boiled form and various processed products); and risk management. Understanding these priorities is fundamental for the promotion of new varieties in the future.

Farmers rely on production, end-use and cultural functions when using and combining their varieties. Previous studies in different countries in sub-Saharan Africa reveal that tolerance to stress (climate change, biotic stress, low soil fertility), presence of high yields, production rate and organoleptic characteristics are all criteria for adoption of varieties by producers.[47-52] Other authors mention the specific and detailed quality requirements of a variety to produce fufu (couscous), boiled cassava, or bâton de manioc.[1,15,17,48,49] Diverse specific requirements for each of these products mean that it is rather impossible to breed all required traits into just one or two varieties suited to all products. For breeders to focus more specifically on the type(s) of variety for which farmers and processors express need would be a much more efficient strategy. These needs are also likely to be perceived in the context of the combination of varieties they already grow.

In the villages in the Central region, the strong linkage between complementarity and end use is justified by the purpose of most of the production. Table 3 shows that most producers in this region are *producer–processors–traders* (80%). In Zoguela, the complementary nature of crop management is a strong motivation for the producers, as most of them are *producer–traders*. In each zone, producers seem to rely on key forms of complementarity. However, this does not exclude the existence of additional forms of complementarity, because: (i) cassava production is primarily grown for *partial* consumption; therefore, producers who specialize in selling fresh roots can also process cassava for family consumption and vice versa; (ii) producers are almost all exposed to the same production risks (phytopathological, climatic, pedoclimatic and entomological); (iii) in view of the important place that cassava has in the households of farmers (anchored in the food habits), it is necessary to have roots available throughout the year; and finally, (iv) the varieties that producers possess often have histories that some of them are keen to preserve. Irrespective of geographical location, farmers resort to complementarity related to risk management.

The complementary framework (Fig. 4) developed in this study, together with cassava farmers and other crop users along the value chain, can guide the varietal prioritization process. It can also help in designing more efficient dissemination/promotion strategies for new varieties. This approach can most certainly also be useful to other crops where varietal complementarity is a key attribute of the cropping system.

The dissemination of improved cassava varieties has been underway in Cameroon for more than three decades, aimed at producing more, enhancing resilience of production systems and, ultimately, ensuring food security. But their adoption remains a real challenge. In this study, four forms of varietal complementarity that constitute strategies for the experimental and continuous use of varieties for farmers have emerged: use-related, risk management-related, harvest management-related and cultural. The use of these forms of complementarity translates into the combination of varieties according to various criteria (identity of the plant material, type and length of the cycle) with the aim of satisfying the different organoleptic, production and cultural functions sought by farmers. It is acknowledged that other forms of complementarities may likely exist.

Moreover, the mechanism of complementarity was observed during both the experimental and the continuous use stages of the process of farmers' adoption of new varieties, highlighting that this mechanism is part and parcel of farmers' farming strategies.

These findings highlight the need to rethink approaches to breeding and disseminating improved cassava. We propose, prior to the actual dissemination of candidate varieties, to profile the producers in the target areas with regards to the combination of varieties they cultivate, and document if the variety portfolio changes among different social groups (and gender within these groups) to increase social impact. This will provide information about the type of function that is most needed. After that the list of required traits to properly fulfil that function can be developed. For example, if farmers like both early and late bulking varieties, which of the two types should be prioritized/improved? Which type is most needed to complement or partially replace the current set of varieties farmers have? As breeders are limited by the number of breeding pipelines because of the high costs involved, this prioritization is therefore key to optimize impact and use of new varieties. This also implies reconsidering the presentation of new varieties to farmers.[20] We propose that new varieties are presented to farmers in a process that emphasizes *addition* (complementarity) rather than *replacement*.[53] Understanding potential functions can thus help breeders to tailor pipelines better, and even select across pipelines as appropriate to fully meet needs of users in defined market segments. Breeding of cassava is based on heterozygous progenitors – preventing conventional backcrossing[54] – which results in a large segregation where suitable varieties for one pipeline can emerge in another.

Farmers are generally very attached to their varieties because of what these varieties have provided for them after years of experience. However, production conditions, processing and distribution systems, and market demands are subject to change. And with those changes, farmers may benefit from experimenting with new varieties from dissemination programs, even if they have often experienced limited benefits in the past. Our proposed strategies can lead to well-defined market segments and corresponding breeding product profiles, thereby highlighting the varieties' functions, aimed at positive social/gender and environmental benefits, including biodiversity. These goals, based on optimal varietal complementarity, are crucial target outcomes for the public breeding sector.[55]

AUTHOR CONTRIBUTIONS

Conceptualization: H.N.T.T., G.H.F.P., S.M., B.T. Data curation: H.N.T.T. Formal analysis: H.N.T.T., D.C.M.Y. Funding acquisition: B.T. Investigation: H.N.T.T., D.C.M.Y. Methodology: H.N.T.T., D.C.M.Y. Project administration: B.T. Resources: B.T. Supervision: G.H.F.P., S.M., B.T. Writing ± original draft: H.N.T.T., D.C.M.Y. Writing ± review & editing: H.N.T.T., G.H.F.P., D.C.M.Y., S.M., B.T.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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