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Review

Biofortification in Nigeria: A systematic review

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Abstract: This paper classified the delivery strategy of pro-vitamin A biofortified crops in Nigeria and characterized the adoption pattern, determinants, and constraints to adoption. Forty papers were reviewed based on delivery strategies and organized into nine categories with cost effectiveness having the highest number of papers mentioned while sustainable approach has the least. Delivery authority, type of breeding technology, location-specific variable, farmland ownership and yield of improved varieties were determinants of adoption of biofortified cassava varieties stated in the papers. Major constraints to adoption included availability of resources, enabling environment for biofortification and undesirable traits due to instability of vitamin A during processing. The study concluded that the delivery strategies are similar to Harvestplus approach. Collaboration between Harvestplus and other agricultural research institutes in Nigeria was recommended.

Keywords: adoption; biofortification; constraints; delivery strategies; determinants

1. Introduction

The World Health Organization (WHO) documented that the number of people suffering from different forms of micronutrient malnutrition across the world is about 2 billion [1]. Globally, one out of three people is micronutrient deficient which poses a negative health implication [2,3]. In 2016, 22.9 per cent of under age-five children worldwide were stunted, one-third of these stunted children were in sub-Saharan Africa within which West and Central Africa account for 33.5 per cent [4]. Such is the menace of malnutrition and its overwhelming effects. An undernourished mother is likely to give birth to an undernourished child, thus furthering the vicious cycle of under nutrition and poverty. United Nations International Children Emergency Fund (UNICEF) and World Health Organization (WHO) in their acknowledgement of this threat continue to push for a scale-up in nutrition interventions especially for this group of vulnerable persons during the pregnancy and child

development stages [5]. Furthermore, Bouis et al. and Uchendu et al. averred that micronutrient deficiencies may lead to increased morbidity and mortality especially among women and children, weak cognitive/brain development with serious implications on learning capacity and earning potentials [6,7]. Micronutrient and vitamin deficiencies (Vitamin A, iron, iodine, zinc and folic acid) are prevalent among women and children in low- and middle-income countries [7]. In sub-Saharan Africa, vitamin A deficiency is one of the most severe public health problems [6,8]. Vitamin A deficiency (VAD) has been identified as one of the major factors of early childhood mortality. In 2013, VAD was recognized as a public health problem by WHO with its highest prevalence (48 per cent) in sub-Saharan Africa [9].

In Nigeria, Maziya-Dixon et al. estimated that 24.8 per cent of preschool children and 13 per cent of women of childbearing age are vitamin A deficient [10]. Also, Maziya-Dixon et al. reported that about 30 per cent of under-five children and 20 per cent of pregnant women in Nigeria are vitamin A deficient [11]. Vitamin A is an important vitamin involved in vision, cell differentiation, synthesis of glycoprotein, reproduction and overall growth and development of the human body [12]. Its deficiency poses a serious public health challenge especially in developing countries of Africa of which Nigeria is well affected. Vitamin A deficiency can lead to mortality or cause a breakdown in the immune system thus predisposing individuals to deadly diseases like measles and diarrhoea [13]. Several methods have been adopted to address vitamin A deficiency in Nigeria. They include nutrient supplementation (pharmaceutical), home food fortification and condiments-fortification of staple foods and biofortification [7]. However, the reach and coverage (especially in rural areas) of initiatives promoting nutrient supplementation, home food fortification and condiments-fortification of staple foods is inadequate, hence the need to biofortify cassava, an important staple food, which constitute significant portion of the diets of many rural dwellers in Nigeria. Africa is the largest producer of cassava in the world with over 54% of the total production, and with Nigeria taking the global lead with a production of about 54.8 million MT in 2014 [14]. Cassava is grown and consumed in all agro-ecological zones of Nigeria.

Biofortification is defined as "the enhancement of micronutrient levels of staple crops through biological processes such as plant breeding and genetic engineering" [15]. Biofortification of staple crops represents a major strategy to tackle the problem of micronutrient deficiency and enhance the availability of vitamins and minerals for people whose diet are dominated by less dense nutrient food [16]. The development of bio-fortified crops will help complement efforts made by the Nigerian government (such as fortification of wheat and maize flour, sugar and vegetable oil with vitamin A) to address vitamin A deficiency by delivering vitamin A through a staple food consumers eat on daily basis thereby meeting up the daily needs of vitamin A for children and women—most vulnerable group.

Biofortification uses advanced technology (breeding and genetic engineering) independently or in combination in selecting crops to add nutritional value by increasing the content of micronutrient, bioavailability of nutrient and its cost effectiveness. Biofortification is identified as an advantageous approach due to its long-term cost effectiveness in delivering micronutrients once incorporated into the plant food varieties. It has far-reaching ability to make micronutrients available to the underserved rural populations who cannot afford other forms of fortification and micronutrient sources, but survive more on staples [17]. Modified crops possibly may offer food-based interventions if fully adopted and accepted, and could reach the remote populations with micro-nutrient deficient diets.

This review concentrated on the biofortification of food crops with vitamin A as this is the target micronutrient for the target crop (cassava) which was internationally recommended, developed and released (in collaboration with national agencies) approved for Nigeria [18]. This choice is further based on the actual implementation, dissemination, commercialization and well establishment of this particular micronutrient crop since 2011 for Nigeria. The broad objective of this research was to conduct a review progress of vitamin A micronutrient biofortification interventions on food crops in Nigeria through various scholarly documentations. The specific objectives of the research were to:

(1).classify the delivery strategy of pro-vitamin A biofortified crops in Nigeria;

(2).characterize the adoption pattern, determinants and constraints of the biofortified food crops across Nigeria.

2. Methodology

The study is based on Nigeria, a country comprising of 36 States and the Federal Capital Territory. The entity Nigeria is a Federal Republic on the Southern Coast of West Africa, bordered by Cameroun to the East, Chad to the North East, Niger to the North, Benin to the West and the Atlantic Ocean to the South. It is in the tropics with variations in temperature and rainfall from the Northern to the Southern part of the country. It is the most populous of Africa. Nigeria has diverse climates with variations in vegetation from the tropical rain forest in the south to the dry savannah in the north. Hence, it supports a host of crops-cocoa, oil palm, rubber, coffee, cotton, yam, cassava, cocoyam, sweet potato, melon, groundnut, rice, maize, cowpeas etc.

In a bid to improve vitamin A micronutrient availability in Nigeria, fortification of various staple food meals was approved as far back as 2000. Crop development activities with respect to biofortification, was initiated in Nigeria in 2003 at the International Center for Tropical Agriculture (CIAT) and the International Institute of Tropical Agriculture (IITA) in collaboration with HarvestPlus project. Their work heralded the approval and release of certain improved crop varieties in the Nigeria space, like the pro-vitamin A biofortified cassava in 2011 (the most frequently used in this region). However, to meet up the WHO recommended average requirement of vitamin A intake, the Nigerian political system licensed biofortified crops in the Micronutrient Deficiency Control (MNDC) guidelines of 2014. Therefore, it is a substantial assumption that vitamin A biofortified crops are consumed in all parts of Nigeria.

Articles published on biofortification of staple food crops in all states of Nigeria were downloaded and assessed to identify studies reporting crop development and adoption/acceptance of biofortified crops, progress made, challenges encountered, lessons learned and intervention policies. Published studies generated were screened based on these pre-defined themes and articles not reporting findings on these themes were excluded. Finally, full texts were re-evaluated for data extraction. For objective one, the various delivery strategies for pro-vitamin A biofortified food crops as observed in the various places of Nigeria were itemized and counted to determine the number of papers where such strategies were mentioned. These are in principle certain aspects of three major delivery systems as used by the HarvestPlus project. The project is working with over 60 partners drawn from government, private sector operators and civil society groups to fight hidden

hunger by promoting pro-vitamin A cassava and maize in Nigeria[1]. To achieve specific objective two, the researchers identified, through literature, all the adoption patterns, determinants of adoption and the constraints to adoption as portrayed in the articles concerning pro-vitamin A biofortified crops across Nigeria.

3. Analysis of findings and discussion

3.1. Classification of the delivery strategies for pro-vitamin A biofortified crops

The dissemination and distribution of the pro-vitamin A biofortified crops were not without a technical approach from the various delivery agents involved. It was, in reality, a systematic process that involved particular strategies. These were duly recognized by various studies for the Nigerian experience. The number of papers where the delivery approaches were documented was counted, expressed in percentage of the total number of articles reviewed and presented in Table 1.

Table 1. Delivery strategies for pro-vitamin A biofortified crop mentioned per category.

Delivery strategy	Number of papers mentioned	Percentage
Use of potential crop	5	12.5
Cost effectiveness	7	17.5
Local integration	6	15.0
Seed multiplication	8	20.0
Awareness creation by extension and other stakeholders	7	17.5
Public-Private partnership	5	12.5
Sustainable approach	2	5.0
Total	40	100.0

Note: Source: Authors' categorization.

These strategies are succinctly aggregated into the broad headings and described as is indicated by the various literature.

3.1.1. Use of crops with pro-vitamin A potentials

This involves a basic method whereby certain crops with the genetic advantage/innate ability to retain and transmit vitamin A, i.e., it's bioavailability, are selected as choice crop for plant breeding and dissemination of this nutrient [18,19]. This is, in fact, one of the major strategies of HarvestPlus, the pro-vitamin A biofortified cassava crop programme in Nigeria. Crops like rice, sweet potato, maize, cassava are selected due to its high conversion rate of β-carotene into usable vitamin A [20]. Cassava was mainly selected as the foremost crop for biofortification by 2011 in Nigeria, as it presented a feasible means for vitamin A delivery partly by reason of its well-known carotenoid content [21,22], high and heritable carotenoid content in cassava [23]. Subsequently, there came the

[1] https://www.harvestplus.org/where-we-work/nigeria

release of pro-vitamin A biofortified maize (2012) and projections for the sweet potato variety in Nigeria [22,24].

3.1.2. Cost-effective approach

Strategies employed in biofortification are usually planned to suit the target populations; building on the important regularly consumed crops of these target groups (mainly the poor), taking into account the major crops (mostly staples) consumed and grown by them. Cost-effectiveness analysis by various authors [16,25,26] suggests biofortification to be the cheapest and best solution to micronutrient deficiency in developing countries reaching the rural people, who can even have these nutrients now in their farming fields. Hence, the use of staple food crops as against the more expensive non-staples. Cassava a major staple food consumed in most parts of Nigeria [27–29]. Therefore, the biofortification of cassava with β-carotene has potential to provide vitamin A in the diets of rural dwellers spread across Nigeria and contribute to combating vitamin A deficiency in the country [30,31].

3.1.3. Local integration and seed multiplication

Pro-vitamin A biofortified cassava varieties were first developed through breeding techniques by international organizations that then link-up these new varieties to the local research institutes and agencies to aid in seed multiplication and dissemination. Harvest Plus in partnership with CIAT developed new cassava varieties which were then released to the International Institute for Tropical Agriculture (IITA) to assume breeding operations and scale-up programs in Nigeria, and officially integrated it into the activities of National Root and Tuber Crops Research Institute (NRCRI) of Nigeria for seed multiplication and local adaptive breeding [19,28,32–34]. Harvest Plus-Nigeria and its partners contracted and collaborated with the various concerned agencies at start-up, to coordinate the introduction and seed multiplication of pro-vitamin A biofortified cassava varieties in the foremost four Nigerian States-Oyo, Imo, Akwa Ibom and Benue States—(entry points) representing the various regions [35]. One important revelation is that sufficient seed supply is a delivery strategy and was achieved through seed multiplication to ensure farm household coverage in Nigeria with involvement of both public and private sector [28,36–39]. Delivery channels identified include seed production and dissemination, direct promotion and distribution of free bundles, farmer to farmer distribution, marketing by commercial producers and company incentives [39]. This is characteristic of the multiplication and dissemination channel outlined for other biofortified crops like yellow maize, orange flesh sweet potato [40]. Release/multiplication of pro-vitamin A cassava varieties started in 2011 in 10 Local Governments in the four pilot States [18,28].

3.1.4. Use of extension services programmes and other stakeholders

The use of extension workers, who organize agronomic training and other programmes on the pro-vitamin A cassava varieties for farmers is one popular delivery approach. Since the release of pro-vitamin A cassava varieties, about 1000 extension agents have been trained and equipped on efficient seed multiplication and distribution strategies to farmers in Nigeria with additional promotional strategies of distributing free stem bundles to smallholder farmers [28,35]. Interestingly,

Harvest Plus also built on existing cassava extension pathways including those used by World Bank and the International Fund for Agricultural Development in Nigeria, for the dissemination of biofortified pro-vitamin A varieties [33]. At the point of release of the vitamin A cassava varieties, Harvest Plus project partnership used the instituted pilot take-off places in Oyo, Imo, Akwa Ibom and Benue States as a hub to reach-out to other States in Nigeria.

Creating awareness was also an integral part of agricultural extension service and the programmes of other stakeholders. This involves the creation of a knowledge base for the biofortified products among the target population and increasing demand through awareness and branding campaigns [19]. Awareness of biofortified cassava through effective marketing was found to influence the adoption and sustainability of the market in Akwa Ibom State [41]. This finding corroborates the finding of Ironkwe et al. that adequate knowledge and awareness significantly affect adoption and delivery pattern [42]. Nutritional information on the pro-vitamin A biofortified cassava which has included are used in target villages. For instance, in Oyo State, the number of women processing vitamin A cassava increased from 5 in 2014 to 36 in 2016 due to awareness creation by extension agents and a radio program aired to inform listeners on the benefits of pro-vitamin biofortified cassava [28]. Also, the Nutritious Food Fair which brought together different stakeholders to establish linkages for biofortification purpose was initiated in 2015 [28]. The entertainment industry, which is believed to have the attention of up to 50% of Nigerians, was not left out as Nollywood made films (yellow cassava, Dada Oni Paki) promoting the importance of pro-vitamin A biofortified cassava varieties [28]. Given a combination of these strategies, it is believed that over 50 million Nigerians have been informed of pro vitamin A cassava varieties, which in turn increases consumer demand.

3.1.5. Scaling-up by public-private partnership delivery strategies

This system involved the combination of public delivery agents with private (commercial) deliveries to further increase the spread and diffusion of the pro-vitamin A biofortified cassava [19]. Harvest Plus initially established partnership with various Nigerian government bodies—Ministries of Agriculture and Health, and agencies—IITA, National Root and Tuber Crop Research Institute (NRCRI), National Agricultural Research Institutions [22,40]. Through this, public agents freely distributed the first set of multiplied cassava stems in the first four pilot states by way of field trials and contact farmer training [22]. Since the target was to widely increase the acceptance/adoption of these varieties, the farmers were encouraged to multiply the stems and share with other farmers while also commercializing the distribution of the biofortified pro-vitamin A cassava varieties [28]. This strategy worked as the varieties immensely diffused across the Local Government Areas (LGAs) of the pilot States and then to 18 other States by 2015, with a large area land in cultivation for the production and commercialization [22,28]. The share of commercial (private) stem multiplication outlets has also well exceeded that of the public sector [43].

3.1.6. Long term sustainability approach

A sustainable market was found to be a useful delivery strategy. This was achieved through creating and building consumer demand through marketing, awareness campaigns, product development and distribution outlets, to strengthen demand and supply of biofortified crop for a

sustainable market share [28]. Value addition and product development were used as sustainable market strategy, such that foods and confectioneries were developed using pro vitamin A cassava in Benue and Imo States which was also a method in establishment of distribution outlets in more than 10 States in Nigeria proving handy in consumer access to this biofortified staple crop [28].

Long-term sustainability through the involvement of stakeholders was another delivery strategy to ensure circulation of biofortified staple crops across Nigeria [39]. Harvest Plus partners with organizations like International Institute of Tropical Agriculture (IITA), National Root Crop Research Institute (NRCRI), Federal Ministry of Agriculture, Federal Ministry of Health, and Colleges of Agriculture and Agricultural Development Programmes (ADP) for continued support in seed production and dissemination of biofortified crops starting from the four pilot States of Oyo, Akwa Ibom, Benue and Imo, scaling up to other States of Nigeria. Biofortification of staple crops have been integrated into the Agricultural transformation agenda of the Federal Government of Nigeria and policies are enacted for continued engagement in a profitable business along the seed crop food value chain. The Federal Ministry of Health also provided support by including biofortified cassava, maize, sweet potato in the micronutrient deficiency guidelines approved by the National Health Council of Nigeria for long term sustainability.

3.2. Adoption pattern of the biofortified pro-vitamin A crop

The adoption pattern of the vitamin A cassava varieties followed through the plan made at its introduction in Nigeria in 2011. With ten (10) LGAs as target points within the four (4) pilot states (Oyo, Imo, Akwa Ibom and Benue) as entry points, the species was easily introduced using promotional and extension services strategies to farmers. Three states (Oyo, Imo, Akwa Ibom) out of the four pilot states where Southern states reflecting the density of the consumption trend of this crop in Nigeria, which also translates to its cultivation pattern due to soil types across Nigeria. Also, some adoption/acceptance studies showed that in comparison Oyo state had highest adoption rate of non-biofortified improved cassava varieties [37]. However, the adoption pattern was seen to gradually spread first (reaching 6 villages each) among the entry states and by 2015 had translated to other States of the Nigeria, covering more than several hectares of farmland cultivation [28]. Coverage was also said to have exceeded the expected spread; where also the commercial (private sector) distribution has far exceeded the public sector [43].

Some literature took into account the adoption pattern mostly at the various state levels, however not many. Udensi et al. assessed the adoption pattern of six improved varieties of cassava in Abia state; the biofortified pro-vitamin A variety (TME 419) among these emerged as one of the highest adopted variety across the state (36.7%), besting the local variety by a large margin [44]. Also, Etuk, Umoh estimated the adoption levels of the pro-vitamin A biofortified cassava varieties in Akwa Ibom where they reveal a high rate of adoption by farmers within the State [41]. Ayinde, Adewumi estimated the average adoption rate of pro-vitamin A biofortified cassava varieties to be about 38.72% [38].

3.3. Determinants of the adoption of pro-vitamin A biofortified crops

Many factors were identified as possible determinants of the adoption or acceptance of the pro-vitamin A biofortified crop in Nigeria. As a result of their findings the following most recurring factors were mentioned:

Table 2. Determinants of Adoption of pro-vitamin A biofortified cassava crops.

Factors	Number of paper mentions	Percentage
Nutritional information	3	7.89
Delivering authority	2	5.26
Certifying authority	3	7.89
Awareness	6	15.79
Extension services and demonstration trials	5	13.16
Access to planting material	5	13.16
Type of breeding technology	2	5.26
Availability of funds	3	7.89
Membership of farmer organisations	3	7.89
Location-specific variable	2	5.26
Farm land ownership	2	5.26
Yield of improved varieties	2	5.26
Total	38	100

Note: Source: Authors' categorization.

There are other determinants which were identified either in a lesser capacity or by not more than one of the literature analyzed viz: Profitability, economic potentials, plant traits, farming experience, main occupation, multi-stakeholder platform involvement, source of inputs, diseases resistance, etc. Some other factors were also categorized as proxies to the ones listed above e.g., education as awareness; ownership of livestock as accessibility of funds [45] same as income of other crops. For the sake of the discussions, these determinants are broadly categorized to include more factors by the author for clarification purposes.

3.3.1. Nutritional information

The visible trait (yellow colour) is one known property of vitamin A biofortified crops so that consumers were well aware that this crop differs from their local (usual) variety. Acceptance/adoption was now based on how well informed they are of its nutritional advantage against the high incidence of the vitamin A micronutrient deficiency in their communities [46]. This nutritional information proved a significant factor in consumer preference and willingness to pay for yellow-coloured pro-vitamin A biofortified cassava crop in Nigeria (especially in Imo State of the South-East) [31,47]. The information of the nutrition and health benefits content and length of nutritional campaigns remains an important factor, just as Bouis et al. indicated its instrumentality in the integration of biofortified food to children's diet, thus increasing adoption [6]. Meenakshi et al. also stated that nutritional campaigns have the potentials of improving the acceptance and willingness to pay (WTP) attributes of people for pro-vitamin A biofortified maize varieties where they are introduced [48].

3.3.2. Nature of delivering authority

The nature of the delivering agency for the biofortified pro-vitamin A cassava varieties presents an interesting aspect in its adoption, given that the cassava sector in Nigeria is mostly driven by

public institutions (e.g., NRCRI) and international agencies (e.g., IITA) [34]. International delivering agency was identified as a driving factor of the acceptance of the pro-vitamin A biofortified cassava varieties in Oyo State [31]. In another adoption related research work [37] the larger number of adopters for the pro-vitamin A biofortified cassava varieties in Oyo state in comparison to Akwa Ibom and Benue states could be attributed to the nature/proximity of the delivering agency—the International Institute for Tropical Agriculture (IITA) domiciled in the Oyo State, Nigeria.

3.3.3. Nature of certification authority

The acceptance of biofortification by the concerned Nigerian government entities by the passage of the Biosafety Bill in July 2011 after much drag paved way for the integration of multi-stakeholders and enhanced adoption and scale-up of biofortified crops [6]. It could be recalled that the non-implementation of this Bill held back the release of these improved varieties; such that with its passage National farming and food systems (IITA-Nigeria, NRCRI, National Agricultural Research Institutes, the Federal Ministry of Agriculture, etc.) were engaged (in collaboration with Harvest Plus) in the stem multiplication and dissemination of pro-vitamin A biofortified cassava varieties across Nigeria starting that 2011. By 2013 due to its widespread and importance, the National Council on Health adopted the pro-vitamin A biofortified crops into the Micronutrient Deficiency Control Guidelines (MDCG) which further enhanced its acceptance across the country. With the inclusion of these agencies in the certification, regulatory and infrastructural support framework for the dissemination of the biofortified crops, it was estimated that up to 80 million Nigerians will have access to these nutritious crops in four (4) years [40].

3.3.4. Retention of superior agronomic traits in biofortified crops

Farmer's preference for good agronomic traits (drought and pest resistance, ease of propagation, etc.) is a crucial factor in adoption especially during initial crop demonstration trials [49]. An important property of biofortified crops is its mineral content (such as wheat and corn fortification with zinc) which bestows the potentials for agronomic benefits, contributing to higher crop yields even in mineral deficient soils [50–52]. Bansode, Kumar mentioned that the vitamin A biofortified cassava varieties introduced in Nigeria are suitable to African environment and resistant to cassava mosaic virus (CMV) and so is cultivated by over 500,000 farmers [53].

3.3.5. Access to extension services and demonstration trials

This factor proved essential in the dissemination and acceptance of the new technology of pro-vitamin A biofortified cassava varieties. During the earlier introduction of these varieties extension was provided to farmers along with promotional free stem bundle packs for (low-risk) field trials and it proved successful because farmers who found it desirable further made commercial purchases to increase the use of this yellow cassava variety and distribute to other farmers [19]. Elsewhere in the research on three states (Oyo, Akwa Ibom and Benue) of Nigeria; majority of the adopters domiciled in Oyo and Akwa Ibom showed high access to extension services; where also participation in demonstration trials organized by IITA and other national scientists significantly

affected the adoption of this vitamin A biofortified cassava varieties in Akwa Ibom [37]. Decentralized field demonstration trials are also identified as key demand drivers to reach the farmers by Bouis and Saltzman [19].

3.3.6. Location-specific variable

Closeness to research institute like IITA was found to increase awareness in Oyo State than Benue and Akwa Ibom States [37]. Location-specific variable was found to have a positive influence on adoption of biofortified cassava in Oyo State and a negative influence in Akwa Ibom. The high adoption rate reported in Oyo may be due to the proximity to research institute like IITA and higher dissemination of information thus increasing adoption of improved technology. This may be as a result of agricultural research centers in Oyo State. Options in oil and gas industry in Akwa Ibom State were found to be the reason for low adoption. This implies that the proximity to research institute and their output is more likely to determine the adoption of biofortified crops in states.

3.4. Constraints to the adoption of pro-vitamin A biofortified crops

This includes all the challenges that are encountered which either slows down or obstructs the dissemination and distribution of the pro-vitamin A biofortified varieties to the target populations in Nigeria.

3.4.1. Availability of resources

The realities of new hybrid varieties and its improved farming system, sometimes introduces certain difficulties for smallholder farmers to adopt; such as this cassava having a low multiplication ratio which is only about 1:5 on rural farms [22] poses a problem for its productivity where the necessary agronomic practices (use of herbicides, fertilizers and farm machinery) is not available to increase multiplication to about 1:30. Similarly, Olatade et al. identified; risks to adoption, access to credit, access to market and to a lesser extent, size of farmland, access to labour supply as limiting factors to adoption of the biofortified vitamin A cassava varieties in Oyo state [54]. HarvestPlus also indicated the need to improve the cost effective nature of biofortified planting materials and need for other complementary approaches to widen the range of biofortified food products. This involves much more financial implication to increase the scope of crops biofortified with vitamin A through breeding so as to increase farmer's choice (beyond cassava) and accessibility through a range of crops [6].

3.4.2. Enabling environment and policies

HarvestPlus raised issues concerning lack of internationally recognized standards and regulations for biofortification as part of the challenges faced with speedy dissemination and better adoption of biofortified crops affecting Nigeria [22]. This stems from the idea that regional biofortification of improved crops and cross-border transfers would have made this possible in countries where the regulations are in place, as only a limited number of breeders exist locally. Also, bureaucratic divisions and protocols between the concerned agencies—Agriculture and Health, presented problems to biofortification implementation [6]. There are also regulation restrictions

attached to introducing and disseminating genetically modified food crops [55], which hamper its efficient adoption. In a review, Oparinde et al. identified the adoption of the improved cassava varieties to be dependent on political changes and policies abounding in Nigeria [34].

3.4.3. Undesirable traits

Severe heating processing methods such as boiling at high temperatures, roasting and frying can lead to large losses of carotenoids and isomerization [56–58]. Cassava is consumed mostly in the form of garri and undergoes such heating processing in Nigeria. Hence, it poses a challenge for the acceptance and marketability of this pro-vitamin A biofortified variety, based on its nutrient. This processing loss between production and consumption has also been identified as a challenge [59]. Also pro-vitamin A cassava varieties have low dry matter content and poundability (a property well sort after by the Nigerian community) compared to the local varieties [22], and presents a major disadvantage to its acceptance by the rural persons. There are also the concerns about the long term environmental effects of these genetically modified/improved cassava varieties which as perceived might be a contributing factor to reluctance in adoption by farmers [60].

Other constraints identified are marketability, price fluctuation and costs related to the distribution of new vitamin A varieties in places [33,35,38,54]. There also issues as it concerns the cropping patterns and the multi-cultural nature of the targeted populations in Nigeria [22], whereby some people still mix the cropping of these improved varieties with the local ones [34,44], thus reducing its multiplicity ability. Also, cases of difficulty in distinguishing the vitamin A cassava improved varieties stem from the local varieties exist [36]. These factors are more or less retrogressive to the dissemination and total adoption goal of the vitamin A varieties.

4. Conclusions

Cassava crop is otherwise the main vehicle used for the delivery of sustainable vitamin A nutrient through biofortification in Nigeria. Research focus in Nigeria on the subject of vitamin A biofortified crops is almost entirely on this crop, due to its effectiveness in coverage, wide cultivation across the country and characteristic β-carotene content. The delivery strategies elucidated through the literature share similarities with the fundamental approach used by one of the major groups (Harvest Plus) involved in pro-vitamin A biofortification of cassava in Nigeria. Their strategy involves three major stages: Introducing the product, Scaling-up production and anchoring the product. These stages can be observed in the following step-wise divisions:

-Introduction of the plant breeding program and seed production;

-Multiplication of the planting material;

-Decentralised demonstration trials and promotional seed packs sharing;

-Information dissemination on nutrition and advantages of the new varieties;

-Scaling-up production of these varieties through multi-stakeholders (government bodies, private sectors and farmers and public-private partnerships).

The adoption pattern is a trend which involves the individual farmers who distribute to other farmers and so it diffuses to other areas and locations. The process involves:

-Reception of free biofortified pro vitamin A cassava varieties during promotion;

-Testing of the new varieties in their farms;

-Buying of these new varieties from commercial traders;
-Multiplication of the stem, production and commercialization.

The major facilitators in the biofortification program have concentrated on this crop (for vitamin A) for Nigeria because of the comparative advantage that abounds; although pro-vitamin A biofortified maize has been introduced earlier too, research on it has seemed to thrive better in other African countries like Zambia, South Africa, etc., and so is its implementation as a tool for eradicating VAD. Recently, the introduction of orange fleshed sweet potato (OSP) has been on the radar for Nigeria, though it is still at field trial stage at the NRCRI, Umudike.

5. Recommendations

From the various research papers reviewed, we can now see the rate of adoption, factors that influence it and challenges to adoption of the pro-vitamin A biofortified cassava crop varieties. The focus has always been on eradicating VAD through a cheaper cost effective sustainable means accessible to even the rural poorer households. To this effect, the multi-cultural setting of Nigeria must be put into consideration; there is the need for crop development and diversification of the vitamin A biofortification of crops to include various crops more acceptable in the different regions (especially in the Northern part). Also, the categories for which the vitamin A micronutrient is most crucial (young children and pregnant women) should be put into consideration in this crop diversification. As a link up to this and the acceptance of biofortification by the Ministries of Agriculture and Health, policies must be put in place to totally integrate all relevant research institutes in the complete biofortification process. Also, at least one branch of the research centers should be located in each state of the Nigerian Federation to supply quick technical and extension services in addition to the immediate release of new technologies to the various states as they come.

Conflict of interest

The authors declare no conflict of interest.

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