IMPACT PATHWAYS FROM SEEDS TO NUTRITION

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November, 2020

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Nabuuma D., Hoang The K., Reimers C., Raneri J., Nguyen Thi Thuy L., Gauchan D., Stomph T., Swaans K. 2020. Impact Pathways from Seeds to Nutrition. The Alliance of Bioversity and CIAT, Hanoi (Vietnam)

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Photos

Cover page: A Dao woman carried her baby while working on a vegetable field in Sa Pa. By Trong Chinh
Third page: Young plants of H'Mong mustard. By Nguyen Xuan Diep / Fruit and Vegetable Research Institute

Acknowledgment and Disclaimer

This publication has been prepared by the Alliance of Bioversity International and CIAT in the framework of Project "Integrated vegetables seed systems development in ethnic minority communities in Northern Vietnam for enhanced nutrition and income security". The project is part of the Netherlands - CGIAR research programme with project number W.08.240.101, which is funded by the Dutch Research Council (NWO).

Contents

Executive summary

To elucidate how, and under what conditions, increased access and use of high-quality seed translates into nutrition security among smallholder farmers, several impact pathways were explored. Given the importance of vegetables for food and income, understanding and improving the seed system has the potential to enhance nutrition and income security. Seeds are an important part of agricultural interventions and this action sought to develop theoretical pathways from seeds to nutrition at household and community levels as a precursor to improving vegetable seed systems and building evidence of the linkages.

Four theoretical pathways from seeds to nutrition were envisioned the **nutrient-dense seed pathway,** the seed diversity pathway, the seed value chain pathway, and the seed security and resilience pathway. 1) The **nutrient-dense seed pathway** assumes that household and community access to seed of nutrient-dense species and varieties enhances their consumption which improves nutrition security. Farmer access to nutrient-dense seed can first be realised by harnessing the seed available within the community, where nutrient-dense species and varieties that meet the nutrient needs and preferences of the community are identified and promoted. The seed can also be sourced from other communities, seed companies, and research organisations that preserve, breed, multiply and market seed, and this can include land races and/or improved seed. 2) The **seed diversity pathway** assumes that household access to seed diversity contributes to the consumption of diverse vegetable species and varieties and hence dietary diversity and nutrition security of the households. Seeds can be acquired through farmer saved seed and seed locally available in the market from seed companies and vendors and seed produced by farmers, and cooperatives. Promotion of seed diversity can focus on diversity already existing in the community and/or the introduction of indigenous or improved species or varieties from other areas that can contribute to seed diversity in the target community.

3) The **seed value chain pathway** assumes that farmer participation in the seed value chain increases household investments in nutritious foods, leading to food and nutrition security. Farmers mobilised in groups or enterprises with adequate knowledge, skills, technology, infrastructure and linkages with other seed value chain actors can improve their resource mobilisation, seed production capacity, and bargaining power which increases the quality of their produce and income earned, which can in turn contribute to household food security. Lastly, 4) The **seed security and resilience pathway** assumes that seed access can be facilitated and enhanced after a shock or stress to support and ensure food security. In the event of natural, climatic and biotic shocks, farmers can utilise self-saved seed stores. If this seed has been affected, they can utilise locally maintained seed in their community through farmer groups, cooperatives, and community seedbanks, and through local vendors and markets. Where shocks have affected several households or the entire community, or in the case of market shocks affecting community access to purchased seed, farmers can access seed maintained elsewhere through exchange and purchase from neighbouring regions (locally maintained seed from other communities), and beyond. These channels are however all limited by the diversity, quality and quantity of seed and the state of the farmer seed networks and seed systems that were available before the shock, and the extent of the shock within the community.

Across the four pathways are several factors that influence the impact of seed system directed interventions on nutrition and food security. These include: a) the diversity, quality, and quantity of seed that is available and accessible to households and communities; b) the functional state of the seed systems (both formal and informal); c) farmer access to resources like land, labour, and capital; d) farmer preferences, knowledge, skills, attitudes, practices, and social networks; e) availability of technical support through extension services and capacity building; f) use of participatory and gender-sensitive approaches; and g) systems, partnerships and policies that facilitate linkages between seed value chain actors, increase access to technology and infrastructure, enable seed certification and protection of seed rights and genetic material, and provide a safety net for farmers. The proposed theoretical pathways can be used to not only design seed system interventions that target nutrition and food security, but also build a solid evidence base for the pathways.

Background

Vegetables are a major source of nutrition and income for ethnic minority groups in Vietnam's Northern highlands. Vegetable production and value chains for fresh retail products offer huge opportunities for development, particularly for women and youth. In 2017, more than 750,000 farmers in the Northern highlands were producing vegetables and this number continues to grow. Production is diverse and offers an important source of off-season vegetables for the capital Hanoi, when winter vegetable production in the Red River delta transitions to rice [1]–[3]. Vegetable consumption has been linked to production especially in areas with poor market access [4] underscoring their contribution to nutrition. The potential of vegetable production is however challenged by limited access to resources such as seed, inputs, infrastructure, knowledge and inadequate value chain linkages [5], [6]. The seed related challenges in particular include limited access to quality, diverse and preferred seed, inadequate knowledge and practices around seed- borne diseases and post-harvest practices, poor seed health, limited quality assurance, inadequate research and development of farmer seed systems, and limited inclusion of ethnic minority farmers (especially women, youth) in seed value chains [5], [6]. Given the importance of vegetables for food and income, understanding and improving the seed system can enhance nutrition and income security. It is on this premise that the project 'Integrated vegetable seed systems development in ethnic minority communities in Northern Vietnam for enhanced nutrition and income security' sought to elucidate how, and under what conditions, increased access and use of high-quality seed translates into enhanced smallholder incomes and nutrition security.

To elaborate how changes in seed systems can translate into food and nutrition security, theoretical impact pathways were explored. The impact pathways from seeds to nutrition build on the existing agriculture to nutrition pathways. The agriculture to nutrition pathways are interconnected and broadly link agriculture to nutrition i) through food consumption from food production, ii) through income from agriculture and how its spent, iii) through the effect of production on food prices, iv) through women empowerment, and v) through the effects of agriculture on national income and economics [7]–[9]. Evaluation of these linkages has revealed mixed results on their impact on nutrition as well as methodological and knowledge gaps [7], [10]. For example, studies in Asia showed that agriculture influences diets even when controlling for income and prices [11] and that while impact on intermediate outcomes like consumption have been noted, there is mixed and limited impact on final nutrition outcomes like nutrition status [12], [13]. Even though studies continue to build and shape consensus on these pathways, there is a lack in the design and rigor required to demonstrate the linkages and hence a need for further research to identify casual mechanisms, types of impact, and cost and sustainability [7], [10], [14].

Seeds are an important entry point of agricultural interventions. Seed related interventions include but are not limited to improving the performance and nutritional content of seeds and/or edible plant parts and enhancing farmer access to and capacity to utilise and maintain quality seed. In fact, provision of seed is a common element in nutrition-sensitive agricultural interventions and studies expounding on the agriculture to nutrition pathways [9], [15]. However, between access to seed and impact on nutrition, lay several household decisions and practices as well as barriers and enablers [16], [17]. Seed systems include a range of technologies, business models, organizational set-ups, and market and non-market institutions that affect the access and use of seeds [18]. Seed production and utilisation includes several technical, economic, social and organizational trade-offs and synergies. For example, trade-offs between cost, quality and market motivations for the producer and between consumption versus market production needs and preferences for the user [18], [19]. Both formal and informal systems possess significant complementarities that are important for smallholder farmers [20], [21]. The formal seed system provides uniform and evaluated seed and is guided by scientific plant breeding and multiplication methodologies by

the public or private sector, while in the informal seed system, farmers conduct seed selection and production [22].

This action therefore sought to develop theoretical pathways from seeds to nutrition at household and community levels as a precursor to improving vegetable seed systems and building evidence of the linkages. Four simplified causal pathways were envisioned (figure 1) from seed to nutrition security and these were the nutrition-dense varieties, seed diversity, seed value chain, and seed security pathways. To build upon these causal pathways, detailed theoretical frameworks of each of these impact pathways at the household and community level were developed based on a review of the impact pathways from agriculture to nutrition, relevant literature, internal project reflection and findings, stakeholder meetings and expert meetings to refine the pathways. The theoretical frameworks presented in this report are oriented towards vegetables, but the findings are applicable to other crops as well. Reference to seed in the four pathways refers to 'true seeds' as well as other starting materials like bulbs, roots, seedlings, etc.

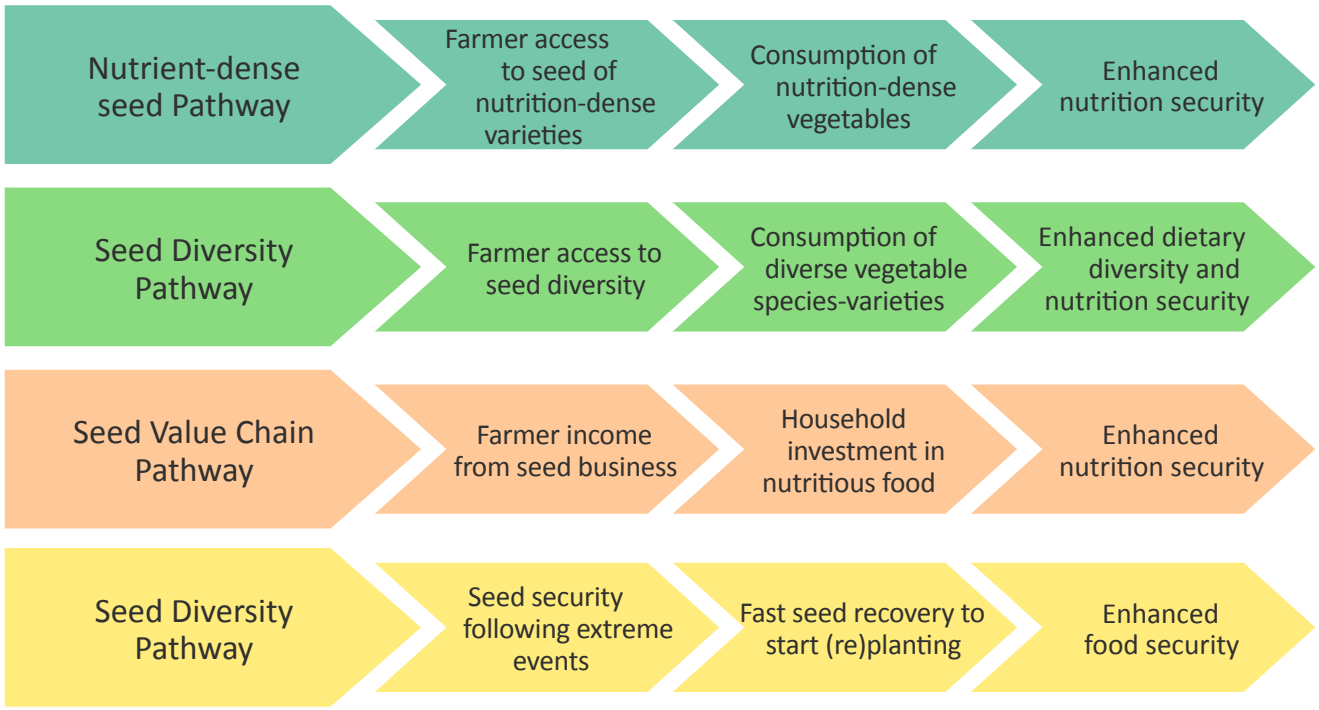

Figure 1 Simplified causal pathways in the project proposal

Seed to nutrition impact pathways

1. Nutrient-dense seed pathway

The **nutrient-dense seed pathway** assumes that household and community access to seed of nutrient-dense species and varieties enhances their consumption which improves nutrition security. Nutrient-dense species or varieties can be traditional or indigenous, neglected or underutilised, or biofortified [25], [28], [42]. In this pathway, farmers can access seed for nutrient-dense species and varieties from those that are available within their community and those sourced from other communities, seed companies, and research organisations that preserve, breed, multiply and market nutrient-dense seed (figure 2). Utilisation of this seed can be enhanced through identification, selection and promotion of nutrient-dense species and varieties, and building farmer capacity on seed saving, production and consumption; promoting processing and/or marketing of nutrient-dense vegetables and their products; and improving farmer access to seed through value chain linkages.

Farmer access to nutrient-dense seed can first be realised by harnessing the **nutrient-dense species and varieties available within the community.** Based on the assessment of the nutrient profiles of vegetables available in the community, nutrient-dense species and varieties that meet the nutrient needs and preferences of the community can be identified and promoted. Tsharing, exchange and saving of nutrient-dense seed can further improve seed availability. Promotion of nutrient-dense species and varieties is considered to be both a cost-effective approach to address micronutrient

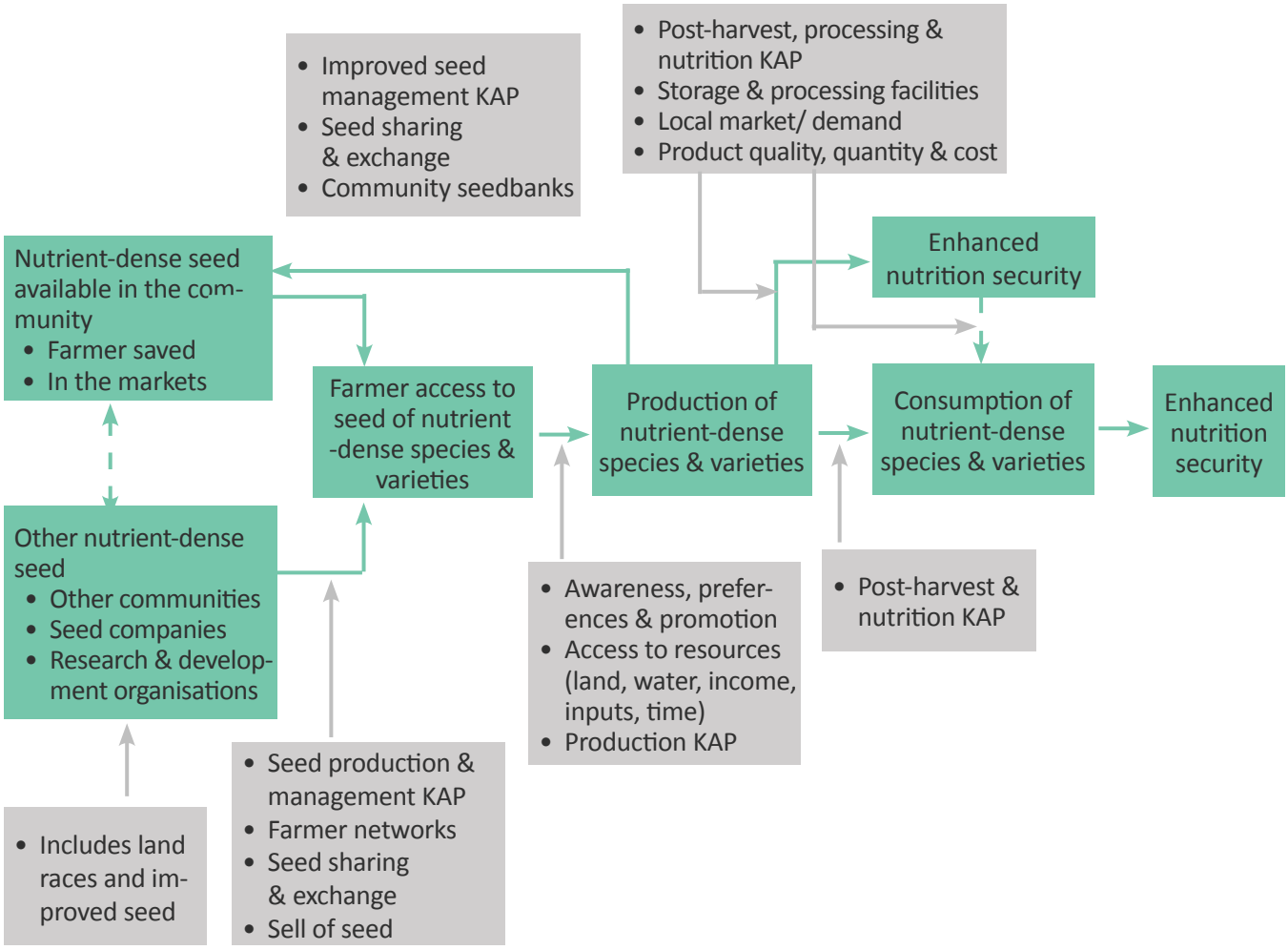

Figure 2 Nutrient-dense seed pathway

Green boxes indicate the main pathway while grey boxes indicate the enabling factors.

deficiencies, but one that also needs complementary interventions like micronutrient supplementation, fortification and biofortification to increase impact [43].

Nutrient-dense seed can also be sourced from **other** communities, seed companies, extension and research/ developmental organisations that preserve, breed, multiply, distribute and/ or market seed. This includes land races, and improved seed. Through these channels, starter seed can be provided through farmer groups and cooperatives for production, multiplication, and dissemination. Farmer involvement in selecting and improving these species and varieties enhances their adaptation and eventual adoption within different contexts.

Biofortification is one approach that has increased farmer access to nutrient-dense seed and improved nutrient intake, diet quality [33], [44]–[46]. However, it has also been noted to negatively affect seed diversity through specialisation and replacement of local or traditional species and varieties [33], [43], [44], and reduce dietary diversity among poor smallholder farmers [47]. It is therefore important that interventions on nutrient-dense species or varieties are complemented with components that affirm dietary diversity and safeguard biodiversity.

Increased availability and access of nutrient-dense seed in turn can lead to increased production nutrient-dense species and varieties. To facilitate this, awareness creation and promotion are needed in order to meet, enhance and address social and cultural preferences. This includes involving and equipping farmers to better access, select, multiply and produce the nutrient-dense foods and incorporate them into their farming systems using sustainable approaches that maximise available resources like land and labour. Improving farmer knowledge and skills on production, post-harvest handling, processing, and preparation supports seed adoption, consumption and impact on nutrition [43], [48]–[50]. This production and consumption in turn supports the saving of nutrient-dense seed.

Increased production can also lead to **marketing of nutrient-dense species and varieties and their processing** to yield value-added products. In addition, the sale of the nutrient-dense vegetables and their products for local consumption further increases their availability within the community which in turn creates demand for seed and vegetable production. As such, the value chain arrangements for nutrient-dense species and varieties can strengthen local availability and access. Marketing and value addition can also increase income for the producers, processors and retailers which can contribute to their food security and household resilience when appropriately used (see section 3). Marketing and value addition however require promotion of the products, adequate access to produce, appropriate storage and processing facilities, adequate knowledge and skills in order to yield quality, affordable and acceptable nutritious products. Where there are underdeveloped markets or farmers have limited market access, the value-added products part of the pathway becomes insufficient. In this instance, promoting the production and consumption of nutrient-dense crops becomes the cost-effective approach [42], [44], [45].

2. Seed diversity pathway

The seed diversity pathway assumes that household access to seed diversity contributes to the consumption of diverse vegetable species and varieties and hence dietary diversity and nutrition security. Seed diversity refers to diverse vegetable species/varieties, in particular, species/varieties from different nutrient-rich food groups like dark green leafy vegetables and vitamin A rich vegetables. Diversity may also refer to species/varieties that differ in seasonal availability for consumption. Interventions promoting seed diversity have shown a positive impact on dietary diversity, dietary quality and food security [23]–[28]. Seed diversity among farmers is built in a number of ways such as, farmers using, saving and creating different varieties using local germplasm and traditional practices to meet different needs [29], and by seeds circulating within the formal and informal seed networks to reach farmers [30].

In the seed diversity pathway, increased and sustained access and availability of seed diversity to farmers depends on two main sources: farmer saved seed (self-saved and/or exchanged within the community) and seed from the market (informal or formal) (figure 3). Seeds in the community can be largely acquired through farmer saved seed, community exchanged seed and seed locally available in the market from seed companies and vendors, seed produced by farmers, and cooperatives, and seed from extension, research and other development organizations.

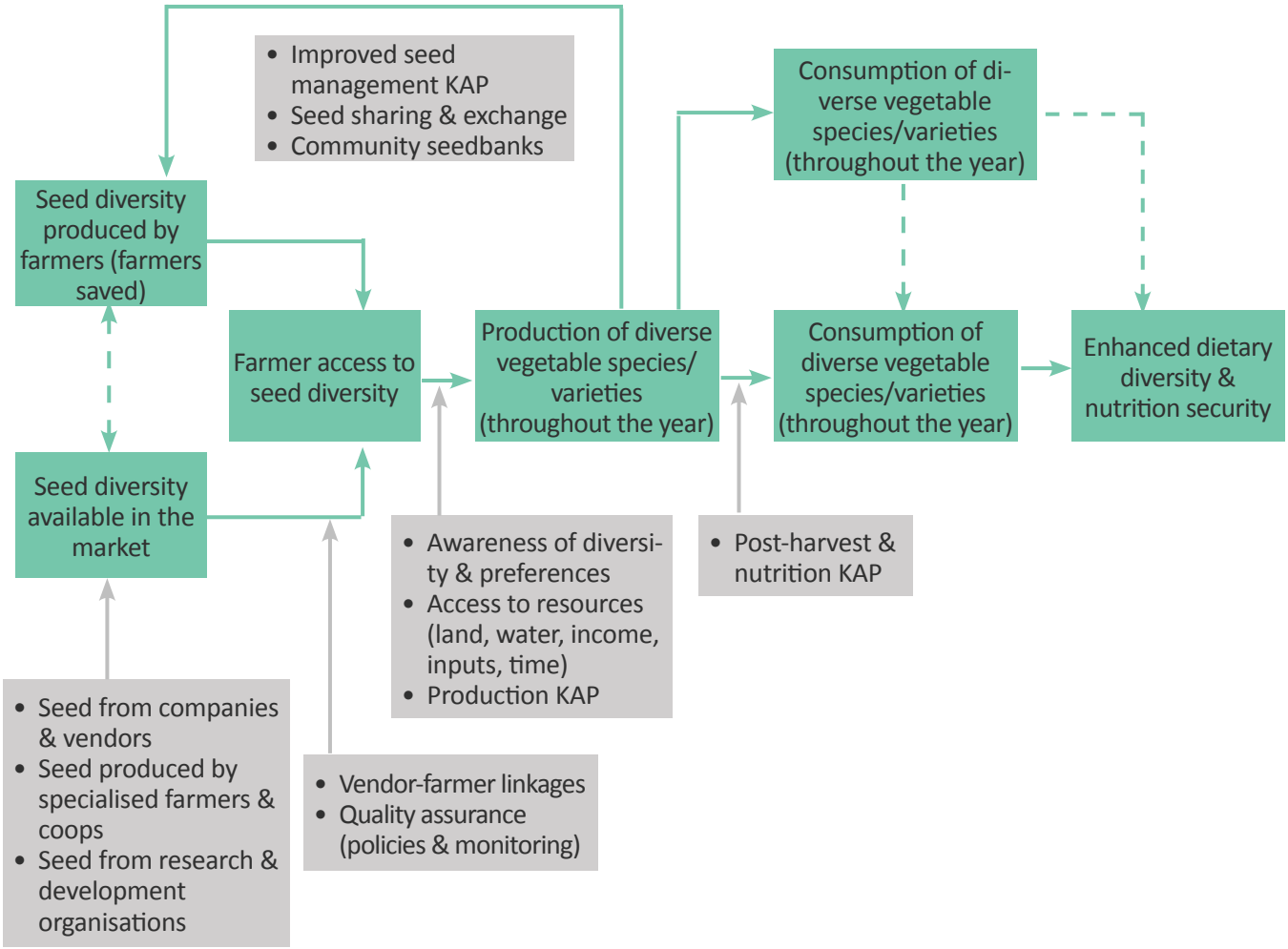

Figure 3 Seed diveristy pathway

Diverse vegetables refer to diverse species & varieties especially nutrient rich vegetables, and vegetables that fill gaps in seasonal availability. Green boxes indicate the main pathway while grey boxes indicate the enabling factors.

Increased access to diverse quality seed can in turn contribute to the production and consumption of diverse vegetables. Potential strategies through which seed diversity can be enhanced include: awareness creation and promotion of diversity in vegetable species/variety production and consumption at household and community level; building farmer capacity in seed production and promoting conservation of local diversity (including neglected and underutilised species) through self-saved seed; promotion of seed exchange through farmer groups and community seed banks; and building farmer networks with seed and production value chain actors. Promotion of seed diversity can focus on diversity already existing in the community and/or the introduction of indigenous or improved species or varieties from other areas that can contribute to the target community needs.

In this pathway, a large part of vegetable diversity is related to the production from **farmer saved seed**[1] that is self-saved and exchanged in the community. It is important that the existing diversity is both sustained and where possible enhanced so that farmers can produce, save, and exchange more seed both in terms of diversity and quantity in turn ensuring seed access for subsequent seasons. This can be supported through awareness creation, promotion of diversity and capacity building on the importance, production and seed management of said diversity. Promoted diversity for example, can include species or varieties that are resilient, nutrient rich, or are available in the lean seasons and can boost stable access to essential nutrients throughout the year. Incorporating indigenous knowledge in capacity building and diversity promotion has been reported to enhance adoption of seeds and their impact on food security and nutrition [28]. Furthermore, households can access seeds of different species/varieties by sharing and exchanging farmer saved seed for example through informal farmer groups and networks. This process can be formalised through (regular) 'seed markets' or even through community seedbanks which are locally managed seed repositories for local varieties. Community seed banks can improve access to, and availability of, diverse, locally adapted crops and varieties, and enhance indigenous knowledge and skills in seed collection or selection, documentation, regeneration, multiplication, storage, distribution and marketing of diverse local and improved seeds. Through partnerships and networking, they also provide a channel for introducing and sharing technologies, information and seeds with both informal and formal seed system actors [31], [32]. Loss or reduction in specie/variety diversity has been reported as a result of introduction of improved varieties [33]–[37], making local diversity conservation important. It further must be noted that farmers often maintain purchased seed for a number of generations before renewing the seed by new purchases. Therefore, introducing diverse species and varieties contributing to seed diversity that allows this practice – saving, exchanging and recycling of seed – may be more appropriate than introducing varieties that cannot be maintained this way but requires seasonal purchases (especially in resource limited settings).

Seed from seed companies and vendors and seed produced locally by farmers, and cooperatives together contribute to the **seed diversity locally available in the market**. Through enhanced linkages between seed companies, vendors and seed producing famers, the market supply of seeds of different species/varieties can be better linked to farmer demand throughout the year. This requires a demand for diverse seeds among farmers and availability of affordable and quality seeds that correspond to this demand. Seed demands not only vary among farmers but may also vary throughout the year, therefore linking the demand and supply can lead to increased access to diverse seeds. An increase in seed diversity on the local market increases the options for farmers to purchase good quality seeds of vegetables. Access to seed locally available in the market is also influenced by the ability of farmers to physically access markets, economically afford sufficient quantities of seed in a timely manner and be adequately informed of the importance and production of the available diversity [38].

Increased farmer access to diverse and quality seed supports increased production and consumption

1 Based on seed system characterization findings among ethnic minorities in Northern Vietnam

of diverse vegetable species/varieties [23], [24]. The level of diversity and quantities produced are however limited by the available resources like land, labour, and capital, and farmer preferences, knowledge, attitudes and practices [24]. Therefore, creating awareness about diversity and nutritional quality of vegetables, and building capacity in sustainable production of seeds, post-harvest handling of vegetable products and seed, and food processing and nutrition, can enhance continued utilisation of the available seed diversity. Actions that improve access to resources and inputs of both men and women farmers through the formation and linkages of farmer groups to input and credit service providers can also support the production.

The enhanced consumption of diverse vegetables can in turn contribute to improved dietary diversity and nutrition security [39]–[41]. One of the outcomes of increased production and consumption of different species and varieties of vegetables is the increased likelihood that they can be accessed more consistently throughout the year thus improving nutrition security. However, given the seasonal limitations of vegetable production among smallholder farmers, the quantities available in the respective seasons can be enhanced together with increasing availability of vegetables with complementary seasonality to fill gaps in seasonal availability.

3. Seed value chain pathway

The seed value chain pathway assumes that farmer participation in the seed value chain increases household investments in nutritious foods, leading to food and nutrition security. The pathway is centred on collective farmer action to access quality inputs, produce and market quality seed through enhanced value chain arrangements (figure 4). Potential strategies through which farmer participation in the seed value chain can be enhanced include: strengthening collective action by farmers to access resources and engage in seed production; building farmer capacity in

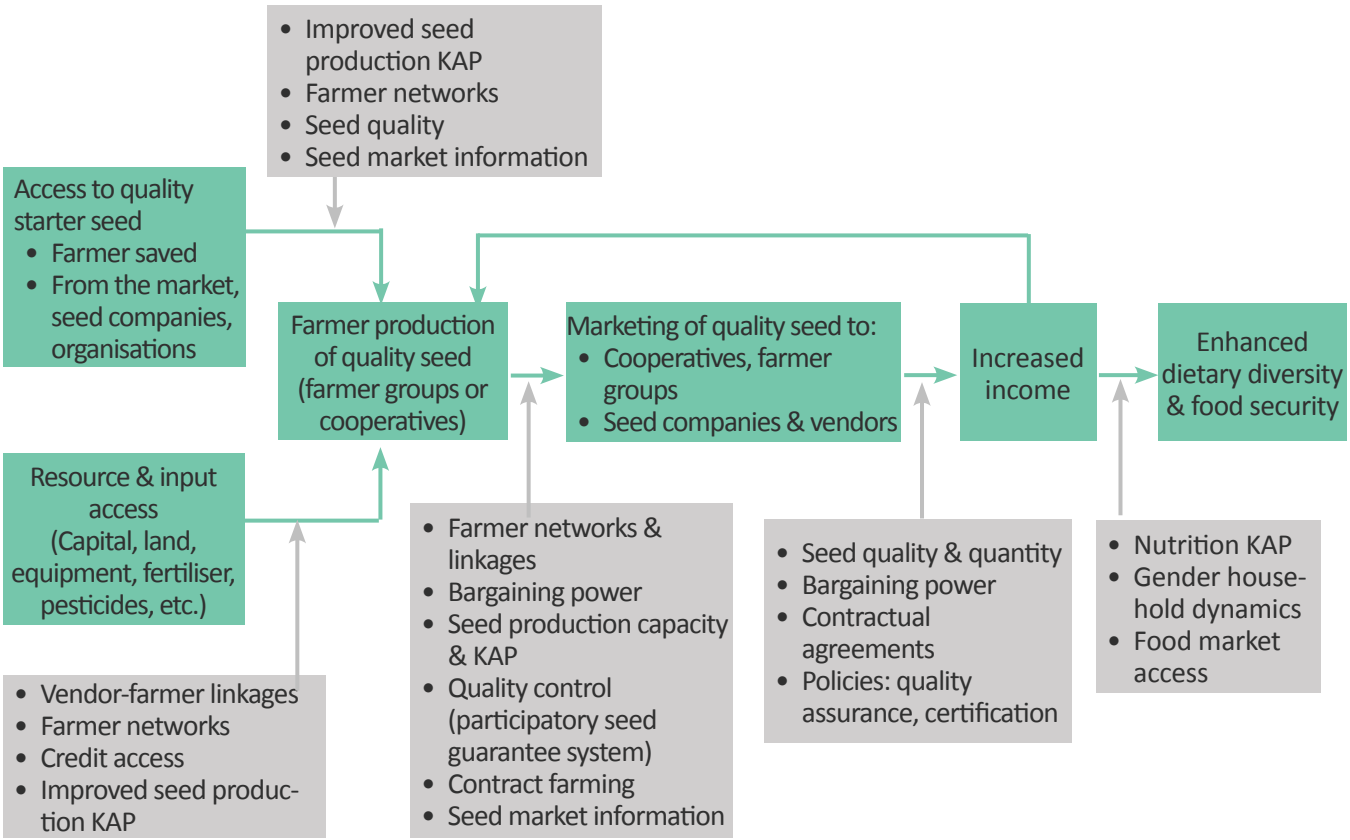

Figure 4 Seed value chain pathway
Green boxes indicate the main pathway while grey boxes indicate the enabling factors

seed production and marketing; strengthening linkages between farmers and other seed value chain actors; improving seed quality assurance through policies & seed actor capacity building; and building farmer and household capacity in nutrition.

The seed value chain pathway assumes that farmer participation in the seed value chain increases household investments in nutritious foods, leading to food and nutrition security. The pathway is centred on collective farmer action to access quality inputs, produce and market quality seed through enhanced value chain arrangements (figure 4). Potential strategies through which farmer participation in the seed value chain can be enhanced include: strengthening collective action by farmers to access resources and engage in seed production; building farmer capacity in seed production and marketing; strengthening linkages between farmers and other seed value chain actors; improving seed quality assurance through policies & seed actor capacity building; and building farmer and household capacity in nutrition.

Small holder farmers, especially when organised in groups and cooperatives, can increase their capacity to produce and sell quality seed to other farmers, cooperatives and seed companies [51], [52] (figure 4). Working in groups and building linkages with other seed value chain actors is likely to improve access to resources, ensure demand is met for example through seed aggregation, and increase seed sale price through increased bargaining power. This can be facilitated through developing and strengthening public-private partnerships, e.g., with: i) input suppliers and financial services to improve access to quality inputs and credit, ii) seed companies and vendors as contracted seed suppliers which ensures guaranteed market and price, and iii) extension services that provide technical support [51], [52]. Farmer group resource mobilisation through savings and loans can also increase their access to inputs. The increase in income from seed production further supports continued investment in seed production, as well as dietary diversity and food security. Though increased income improves financial accessibility to nutrition, its impact depends on a number of factors because said income may or may not be directed towards food (especially nutritious food) and healthcare [53]. To achieve dietary diversity and food security from the generated income, farmers need adequate knowledge and skills in nutrition, favourable gender practices related to decision making and accessible food markets that provide diverse, quality and affordable foods.

For seed production to be profitable, farmers need: adequate capacity, knowledge, technology and infrastructure; financial management skills; and timely market information on seed demand, quality and prices, and other inputs. This can be enhanced by: i) systems and policies that facilitate linkages between seed value chain actors in both informal and formal markets, and between actors in formal and international markets (this requires technology and infrastructure to ease communication between actors, and transport and trade of quality inputs, and seeds, while farmers need adequate skills and knowledge on seed variety maintenance, seed production practices including quality control which can be achieved through participatory seed guarantee systems [54]); ii) Policies that provide favourable financial strategies like taxation and subsidies that encourage equitable participation of actors from formal, informal and international seed markets; and iii) Policies that support registration, quality assurance and protection of seed rights and genetic material (e.g., seed certification, standards for quality declared seed, organic seed etc., which improves the quality and value of produce. Depending on the enabling environment, farmers engaged in seed production can reliably participate in the formal market with registered seed and as producers for seed companies or in the informal market with quality declared seed and as producers for informal seed actors).For seed production to be profitable, farmers need: adequate capacity, knowledge, technology and infrastructure; financial management skills; and timely market information on seed demand, quality and prices, and other inputs.

4. Seed security and resilience pathway

The **seed security and resilience pathway** assumes that seed access can be facilitated and enhanced after a shock or stress to support and ensure food security. The pathway is centred on facilitating farmer access to preferred, high quality seed with relevant resilience traits, from seed maintained within and/or outside the community depending on the type and severity of the shock (figure 5). Potential strategies through which seed access can be facilitated after a shock or stress include: promoting and building farmer capacity in seed diversity, resilience traits, and self-saved seed; strengthening community seed networks; and promoting disaster support mechanisms that facilitate seed and input provision in the event of a shock for example through government and non-government systems.

'Seed security exists when men and women within the household have sufficient access to quantities of available good quality seed and planting materials of preferred crop varieties at all times in both good and bad cropping seasons' [38]. The proposed theoretical pathway centres on household and community access to diverse seed that includes preferred seed with relevant resilience traits such as climate resilient, pest and disease resistant, high yielding, early maturing, drought tolerant, and preferably nutrient-rich. At this level, the shocks and stresses drastically affecting agriculture and in turn seed security can

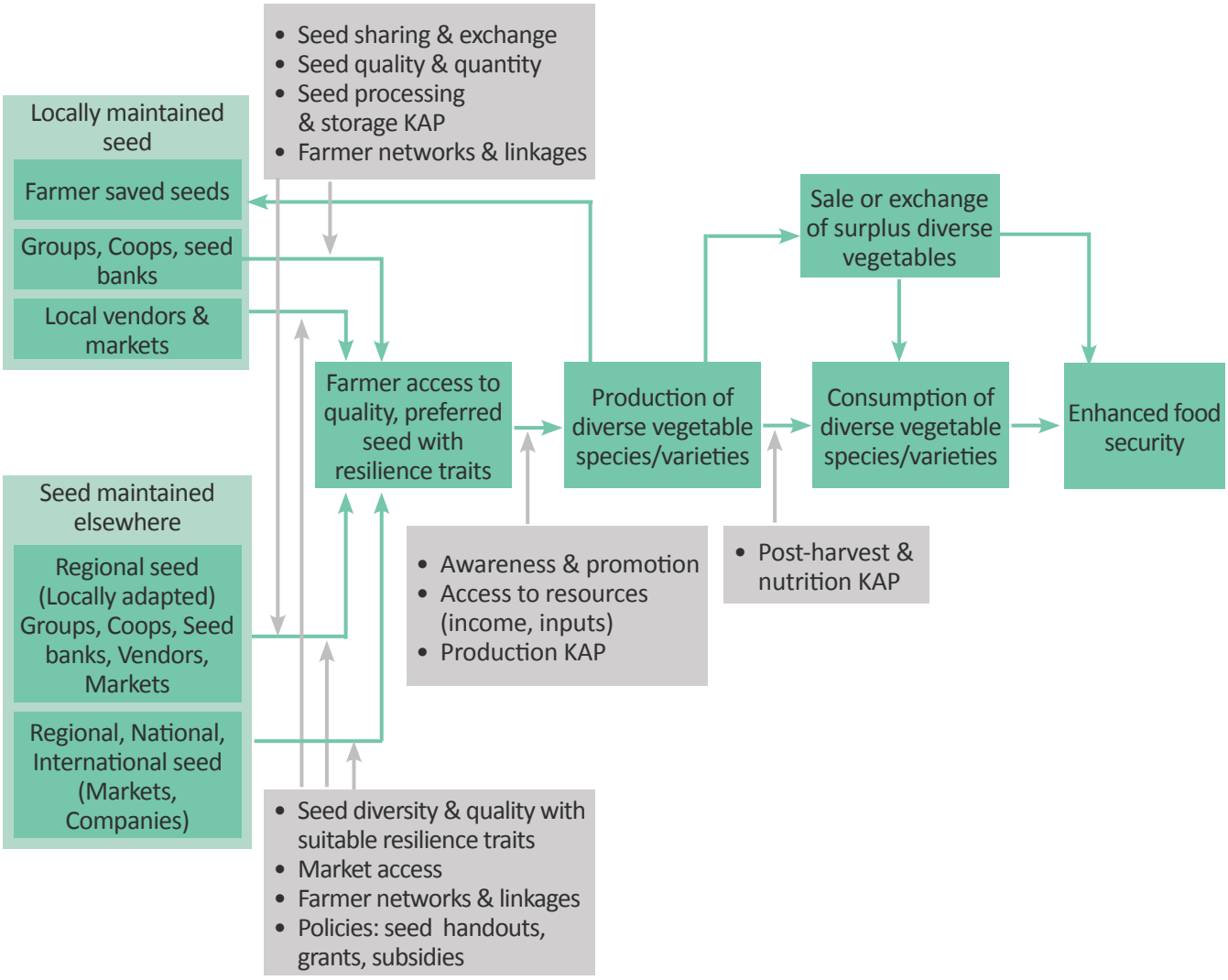

Figure 5 Seed security and resilience pathway
Green boxes indicate the main pathway while grey boxes indicate the enabling factors

include i) natural and climatic shocks like drought, ii) biotic shocks like pests and diseases, and iii) market shocks that affect the functionality of infrastructure like storage facilities, transport, and markets, governance and economic turns that impact trade and prices, and shocks that are result of several factors like the mobility restrictions faced during the COVID-19 pandemic [38], [55]–[57]. The magnitude of these shocks as they affect a household, community and larger region, influences the level of impact on seed accessibility and capacity of recovery. Their impact also depends on the importance of agriculture and in turn seed on the household's livelihood [38].

The pathway envisages farmers having access to largely two categories of seed, first, local diversity that is maintained and accessed from farmer self-saved seed, and locally available seed that is maintained and/or accessed through sharing, exchange and purchase from fellow farmers, local vendors and markets. This includes seed from both formal and informal markets. This category of seed is prone to shocks that lead to loss of availability, diversity, and access. Secondly, farmers can have access to seed diversity that is maintained outside their communities at regional, national and international scales, that is accessed through markets and are largely from the formal sector. While this seed category is less prone to shocks that result in loss of diversity, its access by households and communities can be affected as will be described.

In the event of natural, climatic and biotic shocks, farmers can first utilise local diversity from **self-saved seed** within their households (figure 5). If this seed has also been affected, they can utilise **locally maintained seed** in their community through farmer groups, cooperatives, and community seedbanks, and through local vendors and markets. These channels are limited by the diversity, quality and quantity of seed that was available before the shock and the extent of the shock within the community. The channels are more applicable where existent seed diversity was previously well maintained for example through seedbanks, where community trust facilitated sharing or exchange of seed, and where local seed vendors and markets were reliable, sufficient and with adequate seed.

Where natural, climatic and biotic shocks have affected several households or the entire community, or in the case of market shocks affecting community access to purchased seed for example closure of a seed shop(s), farmers can access **seed maintained elsewhere** through i) exchange and purchase from neighbouring regions (locally maintained seed from other communities), an avenue that can avail locally adapted seed diversity and ii) purchase from regional, national and international markets and iii) seed relief or free seed distribution programs from national and international organizations after disasters. However, shocks and stresses are usually accompanied with limited resources, highlighting the need to facilitate physical and economic household access to seed. The importance of self-saved seed can outweigh the market-purchased seed mainly when households are unable to afford seeds due to the impact of shocks on the agricultural productivity and income [58]. For example, during a year of drought farmers were noted to mainly access improved seeds through purchase, government or non-governmental organisations. This seed access was noted to have increased income among households with good market access and contributed to household resilience [59]. It has also been reported that majority of smallholder farmers (90%) access seed through the informal systems and that 51% of the seed is from local markets [18]. Since different shocks may affect the different seed categories and forms of access described in various ways and magnitudes, to increase resilience, it is important that more than one form of seed access is improved. For example, despite the importance of local markets among smallholder farmers, the formal sector alone is unlikely to meet the varietal needs required for their production, nutrition and resilience goals [18].

To improve seed access, farmer and value chain actor linkages and networks can facilitate communication and delivery of seed where it is required which improves physical access. Secondly, the policy environment can facilitate economic access through insurance and favourable contingency or disaster preparedness plans that include free seed distribution or provision of credit and subsidies for seed and key inputs [60].

In addition to policies that provide credit and subsidies on inputs, input access and food production can be enhanced by community action to mobilise resources for example through village saving and loans and savings and credit cooperative societies (prior to a shock). It is also imperative that the available seed is of high quality, and that the resilience traits are known and can meet farmer needs and preferences. This can be improved through capacity building among seed actors, policy makers, and farmers on seed diversity, resilience traits and quality. Furthermore, efforts must be made to support and ensure gender equal access to seed by explicitly protecting the rights of women farmers to access, control and share the benefits of genetic material & biodiversity management. Together, this contributes to enhanced food security and resilience of both men and women [61], [62].

While seed maintained elsewhere can also be affected by natural, climatic and biotic shocks, the risk of loss of diversity is less when compared to the loss that can be experienced at community level. Diversity can be restored through conserved seed in seed repositories. The seed can however be severely affected by value chain shocks that limit commercial seed production, distribution and marketing. In this case, additional contingency plans that include seed distribution and facilitated transport through national structures are needed.

With increased household and community access to quality and preferred seed with relevant resilience traits, production can resume in a timely manner, leading to consumption and/or sale, which contributes to food security. The production in turn contributes to the available farmer saved seed for subsequent seasons.

As mentioned, strategies through which seed access can be facilitated after a shock or stress will depend on the type and severity of the shock [63], thus providing insight on which parts of the pathway and seed system to intervene or strengthen. The impact of the shocks can be minimised by strengthening the resilience of the seed system prior to shocks for example through profiling and promoting seed with resilience traits, improving farmer seed selection and saving practices, creating or supporting farmer and community seed exchange mechanisms and networks like community seedbanks, and improving farmer to seed value chain actor linkages.

Conclusion

The impact of access to seed on food and/or nutrition security depends on a variety of factors. Across the four pathways "nutrition-dense varieties", "seed diversity", "seed value chain", and "seed security", several enabling (or constraining) factors can be identified, which affect the entry point and impact of each pathway. These include the diversity, quality, and quantity of seed that is available and accessible to households and communities, as well as the existence and functional state of both the informal and formal seed systems. Seed diversity includes the range of seed traits available such as climate resilient, pest and disease resistant, high yielding, early maturing, drought tolerant, or nutrient-density. This diversity moves in tandem with the level of farmer awareness of these traits and their importance and subsequent production. The quality of seeds available significantly affects the production and yield. Farmers need access to high quality seed that can provide sufficient yields and is adapted to the agroecological conditions. It is also important the quantity of seed available can meet the demands in the community across different seasons. The functional state of the seed systems includes the presence of farmer networks and linkages such as farmer groups and cooperatives and how well they are linked to other seed value chain actors like input, financial, and extension service providers and the market which includes seed companies, vendors, cooperatives and farmers that trade seed.

Central to the use of seed is the farmer's capacity to not only utilise the seed and adequately produce, store, prepare and consume the food products, but also their involvement and capacity to act in the seed system for example through sharing, exchange, selection, multiplication, storage, distribution and marketing of seed. This is affected by their access to resources like land, labour, and capital, farmer preferences, knowledge, skills, attitudes and practices, and social networks. Therefore, technical support through extension services, capacity building by organisations, and farmer involvement in seed management and development efforts can positively contribute to the impact of each pathway. Furthermore, systems, partnerships and policies that facilitate linkages between farmer networks and/or seed

value chain actors, improve access to technology and infrastructure that supports seed and food production and marketing, enable seed certification and protection of seed rights and genetic material, and provide a safety net for farmers such as supportive taxation, grants, subsidies, and disaster preparedness plans can also provide an enabling environment.

Also, important to note are the trade-offs and linkages between pathways. Assessment of the target population needs and existing seed systems, can inform the pathway to be strengthened and the most appropriate entry point. For example, within the seed diversity pathway, focus can be placed on nutrient-dense seed, and species/varieties that are complementary in seasonal availability to enhance resilience. Similarly, within the nutrient-dense seed pathway and seed value chain pathway, it is important that interventions are aware of their potential impact on seed diversity and seed security. Source of seed and market access are additional factors that cut across pathways and inform the type of seed used or promoted. Seed access is influenced by the ability of farmers to physically access the markets, economically afford sufficient quantities of seed in a timely manner and be adequately informed of the importance and production of the available diversity. So where physical and economic access are limited, and/or where self-saving of seed is common, interventions are better off promoting seed that can be saved versus that which needs to be purchased at each season.

The pathways can also benefit from the use of sustainable approaches that enable continued and stable access to and use of seed. This can be facilitated through use of participatory approaches that incorporate indigenous knowledge and build farmer capacity and agency; strengthen the mobilisation and formation of farmer groups and cooperatives especially among smallholder farmers; and use of gender-sensitive approaches that improve the participation increase skills to select, exchange and save seeds and enhance access to resources and inputs by both men and women farmers. The pathways are not linear as production of seed requires demand from the market. Increased availability and access to quality seed stimulates its use, and an increase in production, marketing and consumption of different crops and varieties also supports seed production, especially where seed is locally produced or sourced. Therefore, demand creation is important at both ends of each pathway. The theoretical pathways provide an overview of potential strategies and entry points that can be used to design seed system interventions that target nutrition and food security, while at the same time improving them by building a solid evidence base of the underlying mechanisms and conducive conditions.

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Appendix

Table 1 Nutrient-dense seed pathway

Feature	Strategies	Outputs	Immediate outcomes	Intermediate outcomes	Long term outcomes	Nutrition outcomes	Enabling environment
Nutrient-dense species & varieties in the community	• Increase awareness of available nutrient-dense species & varieties • Build HH capacity in seed management; production; post-harvest handling & nutrition • Build farmer groups & networks around seed access	• Increased knowledge, skills & capacity to manage seed & produce nutrient-dense species & varieties, & maintain these seed resources Sharing or exchange of nutrient-dense seed within community	• HH save seed & grow more nutrient-dense species & varieties • Increased community access to nutrient-dense seed	• Increased HH consumption of nutrient-dense species & varieties • HH sell surplus produce for income strengthening community level availability	• Increased/ continued investment in nutrient-dense seed production, processing, marketing & consumption of nutrient-dense species & varieties	• Nutrition security • Food security • (For producers & processors)	• Seed quality & quantity in HH & community • Human capacity (KAP, time) • Social (culture, gender, preferences, networks, trust) • Policies (seed certification, quality assurance, open sourced seed) • Market for nutrient-dense varieties &/or products • Physical (storage & processing facilities, inputs • Capital (financial, labour) • Biophysical (land, water)
Other nutrient-dense species & varieties [2]	• Facilitate access to starter seed (seed to coops, farmer groups etc) • Build farmer linkages to farmer groups & SVC actors e.g. seed companies, research org. • Build farmer capacity in seed management, production, nutrition • Increase awareness of nutrient-dense species & varieties	• Increased knowledge, skills & capacity to produce nutrient-dense species & varieties • Sharing or exchange of nutrient-dense seed within community • Farmers organised as seed producers • Farmers & groups linked to SVC actors (Links to value chain pathway)	• Farmers producing, sharing & selling nutrient-dense seed	• Increased HH consumption of nutrient-dense species & varieties • Increased community access to nutrient-dense seed			
Value addition & markets	• Build farmer & farmer group capacity in nutrition, post-harvest handling, processing • Increase awareness of nutrient-dense species & varieties, & products • Build farmer / farmer group linkages to farmer groups & VC actors e.g. processing companies, markets	• Increased knowledge, skills & capacity to process &/or market nutrient-dense species & varieties, &/or products • Farmers & groups linked to VC actors (under contracts)	• Farmers/ groups producing & selling nutrient-dense species & varieties, &/or products • Farmers have guaranteed market & price	• Farmers earn more income from production & sell of nutrient-dense species & varieties, &/or products • Increased community access to nutrient-dense species & varieties, &/or products			

[2] Refers to nutrient-dense species and varieties not currently readily available in the community or even completely new

Table 2 Seed diversity pathway

Feature	Strategies	Outputs	Immediate outcomes	Intermediate outcomes	Long term outcomes	Nutrition outcomes	Enabling environment
Farmer saved seed	• Build farmer capacity in seed management, vegetable production, post-harvest handling & nutrition • Increase linkages with production actors (e.g. input suppliers, credit access)	• Increased knowledge, skills & capacity to adequately store & utilise diverse seed (esp. nutrient rich vegetables)	• HH save & grow increased diversity	• Increased diversity produced & consumed by HH • HH share/ exchange diverse vegetables • HH sell surplus produce for income	• HH investments in diversity production & consumption • Increased accessibility & availability of quality and diverse seed in households and community • Increased utilisation of diversity in households and community •	• Dietary diversity • Nutrition security	• Seed diversity, quality, quantity existing in community • Human capacity (KAP, time) • Social (networks, culture, preferences, trust) • Physical (storage facilities, markets, inputs) • Capital (financial, labour) • Policies (seed certification, quality assurance) • Biophysical (land, water)
	• Build/ empower farmer groups & networks around seed diversity • Increase awareness of existing/available seed diversity	• Sharing or exchange of diverse seed and/ or vegetables within the community	• Increased access to seed diversity for households in the community				
Seed from market	• Build linkages between farmers & seed vendors to ensure that their supply is linked to demand by farmers • Build farmer capacity in seed production • Increase awareness around seed diversity & quality • Promote seed quality assurance (through policies & seed actor capacity building)	• Increased knowledge, skills & capacity to utilise diverse quality seed • Farmers through groups & cooperatives are linked to seed companies and producers	• Increased availability of diverse seed of high quality on the market (if sold locally, if sold outside the community, it leads away from the pathway) • Increased income from sale of seed produced by farmers – (Links to seed value chain pathway)	• Increased diversity produced & consumed by HH	• Increased investments of specialised farmers in diversity seed production		

Table 3 Seed value chain pathway

Feature	Strategies	Outputs	Immediate outcomes	Intermediate outcomes	Long term outcomes	Nutrition outcomes	Enabling environment
Empowered farmer seed production	• Organise farmers in groups, coops to produce and market seed • Build farmer linkages with SVC actors (seed companies, input & credit suppliers, etc) • -Build farmer capacity in seed production including post-harvest processing, financial management • Facilitate access to quality starter seed • Support seed certification/ quality guarantee • Build household capacity on nutrition	• Increased knowledge, skills & capacity to produce high quality seed • Farmers organised as seed producers (for seed aggregation (including initial post-harvest processing), increased bargaining power, etc) • Farmers & groups linked to SVC actors (for contract farming, seed certification	• Farmers producing & selling high quality seed • Farmers selling at better prices • Farmers have guaranteed market & price for produced seed	• Increased farmers income from seed production • Substantial part of increased income is used to purchase relevant dietary diversity	• Increased dietary diversity and food security • Increased/ continued investment in seed production	• Dietary diversity • Food security	• Market for produced seed (high value) • Seed quality & quantity • Human capacity (KAP, time) • Capital (financial, labour) • Physical (storage facilities, inputs) • Policies (seed certification, quality assurance) • Social (networks, trust, gender) • Food diversity available in markets • Biophysical (land, water)

Table 4 Seed security and resilience pathway

Feature	Strategies	Outputs	Immediate outcomes	Intermediate outcomes	Long term outcomes	Nutrition outcomes	Enabling environment
Locally maintained seed: • Self-saved • Community: Groups, Coops, seed banks • Local vendors & markets	• Increase awareness of seed diversity & resilience traits • Build capacity in seed management • Build/ empower farmer groups & networks in seed diversity, resilience traits storage, sharing &/ or exchange, & mobilising input access	• Increased knowledge, skills & capacity to select, store seed & utilise among seed actors, policy makers, farmers • Sharing &/or exchange of diverse seed with resilience traits • Farmers & groups linked to VC actors over seed • Contingency plans for shocks facilitate vegetable seed access (handouts, subsidies, etc)	• Increased access to diverse seed with preferred resilience traits in community • HH engage in food production after shock	• Increased HH vegetable production • HH sell surplus produce for income	• Increased HH food consumption • HH investments in production & seed saving • Increased availability of diverse seed with resilience traits & its utilisation in community •	• Food security	• Social (institutions, networks, trust, preferences) • Seed diversity, quality & quantity • Human capacity (KAP) • Physical (storage facilities, inputs) • Policies (grants, subsidies, disaster preparedness) • Capital (financial, labour)
Seed maintained elsewhere: • Regional seed (Locally adapted: Groups, Coops, Seed banks, Vendors, Markets) • Regional, national, international seed (Markets, Companies)	• Increase linkages between farmers, seed producers, policy makers, etc • Facilitate economic access to seed through seed grants or subsidies • Build capacity of seed producers on resilience traits						

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