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Technology and Service Bundling and Bundle Performance among Maize Farmers in Eastern DR Congo

BACIGALE, S.B.[1], HELSEN, J.A.[1], OGUNSOLA, D.E.[2] and WOOMER, P.L.[3]

[1]International Institute of Tropical Agriculture, Bukavu, DR Congo
[2]African Agricultural Leadership Institute, Ibadan, Nigeria
[3]African Agricultural Leadership Institute, Nairobi, Kenya.
Corresponding Author: plwoomer@gmail.com

ABSTRACT

Approaches to the bundling of production inputs and accompanying farmer services continues to attract attention as an agricultural development tool. A package of modernizing production inputs consisting of improved and hybrid maize seed and preplant (DAP) and top-dressed (urea) fertilizers targeting 0.25 ha each was assembled and distributed to 2340 small-scale farmers in the Ruzizi Plain and adjacent highlands. Those packages cost about US $138,060 to assemble and distribute (at $59 each). These farmers were also linked to additional services including training on Good Agricultural Practice, access to field and post-harvest support, and the marketing of production surpluses. Maize was planted on 585 ha in October 2024 and harvested in February 2025, the so-called “A Season” within the area’s bimodal rains. Harvest was measured within a random sub-sample of locations. In total, package installation resulted in 2,661 MT of maize, equivalent to 4.6 MT per ha and worth about US $997,718 (at $375 per MT). This resulted in an average 111% yield improvement over farmer practice across all packages. Hybrid maize outperformed a biofortified OPV with WSC Haraka producing 5.5 ± 0.5 MT per ha. Taking into account what the farmers would have otherwise produced using their current practice providing 2.1 MT per ha, a benefit-to cost ratio of 4.2:1 was realized, but does not include farmers’ labor and local delivery costs. Services assisted farmers in treating fields attacked by Fall Armyworm and to mechanically shell their maize harvest, the latter allowing for collective marketing of surpluses. These findings were linked to a desk study on the design and assessment of more complete technology and service bundles as they relate to agricultural transformation in DR Congo. These results suggest that the strategic bundling of production inputs and accompanying services provides a viable entry point for agricultural development.

Key words: Agricultural transformation, delivery model, food security, maize production, Ruzizi Plain, technology bundles

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RESUME

Les approches de regroupement des intrants de production et des services d'accompagnement des agriculteurs continuent d'attirer l'attention en tant qu'outil de développement agricole. Un kit d'intrants de production modernisée composé de semences de maïs améliorées et hybrides et d'engrais de fond (DAP) et d'engrais de surface (urée) pouvant emblaver une superficie de 0,25 ha chacun a été assemblé et distribué à 2340 petits producteurs de la plaine de Ruzizi et des hauts plateaux adjacents. L'assemblage et la distribution de ces kits ont coûté environ 138 060 dollars américains (à 59 dollars chacun). Ces agriculteurs ont également bénéficié des services supplémentaires, notamment les formations sur les bonnes pratiques agricoles, l'accès à la terre et à la gestion post-récolte, et la commercialisation des excédents de récolte. Le maïs a été établi sur une superficie de 585 ha en octobre 2024 et récolté en février 2025, au cours de la saison dite A dans cette région à pluviométrie bimodale. La récolte a été mesurée dans des unités de sous-échantillonnage aléatoires en carrés de rendement. Au total, la livraison des paquets technologiques a permis de produire 2 661 tonnes de maïs, soit 4,6 tonnes par hectare et une valeur d'environ 997 718 dollars (soit 375 dollars par tonne). Cela s'est traduit par une amélioration moyenne du rendement de 111 % par rapport à la pratique locale des agriculteurs pour tous les emballages. Les variétés hybrides de maïs ont surpassé une variété composite biofortifié, avec la WSC Haraka produisant 5,5 tonnes par ha. Si l'on tient compte des 2,1 tonnes par ha que les agriculteurs auraient autrement produit en utilisant leur pratique actuelle, un rapport avantages-coûts de 4,2:1 a été réalisé, mais ceci n'inclut pas la main-d'œuvre des agriculteurs et les coûts de livraison locaux. La campagne a facilité les agriculteurs à traiter leurs champs attaqués par la chenille légionnaire d'automne et à décortiquer mécaniquement leur récolte exceptionnelle, permettant ainsi une commercialisation collective de la récolte excédentaire. Ces réalisations ont été liés à une étude documentaire sur la conception et l'évaluation des technologies et de services plus complets en ce qui concerne la transformation agricole en RD Congo. Ces résultats suggèrent que le regroupement stratégique des intrants de production et des services d'accompagnement constitue un point d'entrée viable pour le développement agricole.

Mots clés : Faisceaux technologiques, Institut Africain de Leadership Agricole, Institut International d'Agriculture Tropicale, plaine de la Ruzizi, production de maïs, sécurité alimentaire, transformation agricole

INTRODUCTION

The design and deployment of technology and service bundles by development projects to smallholder farmers in Africa is recognized as a viable means of agricultural transformation (Abetu *et al*., 2024; Barrett *et al*., 2020; Katungi *et al*., 2024). This is because innovation in crop and land management is required for farmers to solve the complex conditions that prevent their modernization, and these combined solutions are usually beyond their reach (Woomer *et al*., 2024a). In many cases, improved seed must be packaged alongside proven accompanying production technologies and bundled with field and post-harvest mechanization, knowledge management tools and financial services in ways that increase their productivity, reduce their risks and drudgery, and open them to fair and reliable markets and processors, all at once. Their situation is particularly dire in areas where needed production inputs are unavailable through agrodealers or too costly, as is often the case in eastern DR Congo (Angélique *et al*., 2022).

An examination of technology bundling and delivery was conducted in conjunction with the Agricultural Transformation Agenda of the Democratic Republic of Congo Program (ATA-DRC). This Agenda is an initiative of the Office of the President (CCP-PNAA, 2024) and implemented by the Ministry of Agriculture and Rural Development with assistance by the International Institute of Tropical Agriculture (IITA) and the African Agricultural Leadership Institute (AALI). This agenda recognizes that agriculture must serve as the tool for food security and the engine for national development by combatting food insecurity and generating economic opportunities for the Congolese rural population. The Ruzizi Plain serves as one of the operational hubs of ATA-DRC Program, and previous efforts toward agricultural transformation among maize producers there are described by Woomer *et al.* (2024b).

The Ruzizi Plain is located between the Mitumba Mountains to the west and the Ruzizi River to the east. It is part of the larger Western Rift Valley stretching from Lake Albert to the north to the southern end of Lake Tanganyika. The Plain has bimodal rainfall of 600 to 900 mm per year and maximum temperatures of 32 °C. The "long" rains (Season A) fall from October to February, and the "short" rains (Season B) run from February to June, followed by a prolonged dry season. The Plain contains sandy (Arenosols) and clayey (Vertisols) soils mostly of alluvial origin (De Failly, 2000; Rushigira *et al.*, 2023). Agriculture is the major economic activity throughout this area with about 14,000 ha of its total 80,000 ha cleared for cultivation by small-scale farmers (Wikipedia, 2025). These cultivated soils exhibit soil erosion and declining soil fertility (Bagula *et al.*, 2021). The area is characterized by low crop yields and food insecurity and is plagued by a history of civil conflict (Verweijen *et al*., 2020).

This paper serves as an update on the efforts of ATA-DRC to provide needed agricultural technology bundles and opportunities to small-scale maize producers in eastern Congo (Woomer *et al*., 2024b). It is based upon the introduction of improved maize varieties and judicious application of pre-plant and top-dressed fertilizers, in combination with key pest control, post-harvest handling and marketing services. The paper then links this outreach campaign to larger efforts and understandings related to the unfolding area of technology and service bundling in relationship to agricultural transformation (Abetu *et al*., 2024; Barrett *et al*., 2020; Kagabo *et al*., 2025; Katungi *et al*., 2024), including its application within a four-component model that combines improved access to production inputs, on-demand field services, digital information, and improved financial and marketing services. In this way, it provides insights into how best to design large-scale outreach projects intended to improve the lives of small-scale African farmers.

MATERIALS AND METHODS

This bundling outreach project was conducted in parts of South Kivu Province of the Democratic Republic of Congo. This includes the Ruzizi Plain (Uvira Territory) and the northern-adjacent highlands of Walungu Territory. It follows earlier technology delivery efforts described by Woomer *et al.* (2024b). Its activities were conducted during the 2024-2025 growing Season A (October through February) as follows.

Identification and selection of beneficiaries. Farmer recruitment was conducted in collaboration with local authorities, the Provincial Ministry of Agriculture and various farmers' organizations based upon predefined criteria including farm size, vulnerability, gender, commitment to agriculture and membership of farmers' organizations. In total 2340 maize farmers were identified, registered and compiled within a client database.

Package design and assembling production inputs. The input requirements were based upon an intervention area of 0.25 ha per farm. This included 6 kg of certified maize seed, 20 kg of DAP preplant fertilizer, 10 kg of urea top-dressing and farmer instructions in local languages; and assembled within a single, sealed 50 kg woven polythene sack. The rationale for this design is described in Woomer *et al.* (2024b). Maize varieties available to the project included WH 101 Haraka from Western Seed Company (Kenya), WE5117 from AgriForce in Bukavu, and PVA SYN13 OPV from IITA through INERA Mulungu (Bankole and Kolawole, 2023). In total, 2340 maize packages were produced, each weighing about 37 kg. Other packages (960 in total) were assembled and distributed for common bean (*Phaseolus vulgaris*) but their outcomes are not considered in this paper.

Distribution of technology packages. The bundles were transported to 17 local collection sites in the two Territories. These locations included Katogota, Luvungi, Luberizi, Rwenena, Kibirizi, Sange, Runingu, Kawizi, Kiringye, Ndolera and Lubarika in Uvira Territory; and Kamanyola, Nyangezi, Kakono, Bitesi, Irhongo and Luciga in Walungu Territory. Farmers received and signed for the packages, and were responsible for transporting them from the collection sites to their individual farms.

Technical support and training. AALI Youth Brigade members from its Kalambo, Uvira and Walungu Chapters, and IITA technicians from Bukavu were deployed to train the project liaison team in the dissemination of technical messages, and provide bundled services, including information on good agricultural practices and monitoring field performance (AALI, 2023). Farmers were then trained by those secondary trainers in conjunction with the distribution of production input packages and the establishment of local technology demonstrations. The AALI Youth Brigade collaborated with site facilitators, local chiefs and focal points in the villages to disseminate information to farmers and to monitor progress during the planting season. Regular field visits were conducted for advisory support, early identification of problems and technical adjustments. Eight mechanization centers were established across the project to assist in the on-demand treatment of Fall Armyworm pests and machine shelling of maize harvests.

Yield estimation and analysis. The yield square method was used by selecting representative fields to measure crop production within 25 m^2 areas (5 m x 5 m), three replicates per sampled field. Yield was calculated in terms of kg maize grain per ha after shelling by multiplying recovered yields by a factor of 400. In most cases, these yields were obtained from package demonstration sites managed by farmers close to the production input distribution sites.

Monitoring and Evaluation. A participatory monitoring and evaluation system was established by technical teams from the AALI Youth Brigade, agronomists from the Territorial Inspectorate and IITA field technicians. This also allowed the systematic collection of quantitative and qualitative data at each stage (distribution, sowing, growth, harvesting). The use of monitoring sheets and the Open Data Kit (ODK) application allowed for the standardization of field and digital surveys, and yield measurements (Hartung *et al*., 2010).

AALI Outreach Utility applications. The AALI Campaign Design and Analysis Utility described by Woomer *et al.* (2024b) was initialized to calculate campaign impacts and economic returns. Briefly, this MS Excel spreadsheet utility offers a front-end where queries on outreach design are entered (e.g. number of farms, area per farm) and a parameter entry section where the amount and price of production input technologies are loaded (e.g. seed, fertilizer and pesticide rates and cost). Other parameters calculate coordination costs. Users enter the mean yields and value and then calculations are performed. The utility includes a back-end offering a campaign summary and economic analysis. In this case, we initialized 2340 households establishing 0.25 ha each based on the packaged inputs. The yield was compared to the local reported maize yield of 2.1 t ha^{-1} (Bagula *et al*., 2022; Bisimwa, 2023) to calculate increased yield. The total value of maize was calculated based the local price during the maize post-harvest period. This equates to 1 million Congolese Francs (FC) per MT, equal to $375 at the exchange rate of 2667 FC per US $1. The utility's routines and calculations were then inspected for errors and the backend was downloaded as a table in this paper.

Bundling desk study. A desk study was performed to assess critical components of bundling proven agricultural practices, and their applications within agricultural transformation in Africa. It relied upon available published and unpublished reports, and secondary data. A systematic literature search was undertaken using major academic search engines, particularly Google Scholar, revealing documents on bundling best practices and existing delivery models in African agriculture. This approach identified critical bundle components, including production inputs and related support services, as well as the relationships among existing models of bundling best practices and services (Barrett *et al*., 2020). This led to the development of a graphic typology identifying the principal components of bundling and their developmental drivers. In this case, bundles are farmer-centric solutions that increase the productivity of smallholder farms, improve knowledge on agricultural best practices, support access to market and the private sector, while also providing jobs for rural youths as local facilitators. The mobilization process is designed to culminate in farmers and farmer groups expressing their interest in joining future outreach schemes better linked to the private sector through the evolution of business-to-business-to-farmer models as project inputs become better commercialized.

RESULTS

Table 1 shows the training activities conducted in support of the bundle distribution and assessment. In total, there were nine different training actions provided, with smaller training actions associated with project facilitators and larger actions devoted to participating farmers. Note that 416 farmers participated in training on package installation, 902 received training on Good Agricultural Practice and 170 received training in small-scale mechanization.

In all, 1633 were trained, although some may have participated more than once. Of these, 65% were women farmers and 35% were men, however, relatively few women participated in the training of facilitators.

Table 1. Campaign training in the use and assessment of bundled technologies

Location(s)	Training Topic	Participants (no)	Gender (%)	
			Female	Male
Luvungi & Lubarika	Training of trainers	25	8%	92%
Ruzizi Plain	Installing field demonstrations	416	80%	20%
Ruzizi Plain	Good Agricultural Practice	902	70%	30%
Ruzizi Plain	Small-scale mechanization	170	22%	78%
Two territories	Rapid yield assessment	7	0%	100%
Sange & Luvungi	Principles of agricultural transformation	11	18%	82%
Bitesi	Assessment of GAP	15	93%	7%
Kakono	Control of Fall Armyworm	74	57%	43%
Luciga	Maize harvest procedures	13	62%	38%
Total		1633	65%	35%

Note that the registration and training of participants was conducted in conjunction with the distribution of the technology packages and the installation of community-managed field demonstrations. Registration was then linked to the AALI ICT Department that digitized the entire monitoring process through reliance upon ODK tools. This digitalization has not only accelerated the collection of data from the field, but also assisted in corrective actions during the assessment of the bundles. Due to the prevailing conditions of insecurity in the region and the urgency of the seasonal calendar, the registration of some beneficiaries onto the ODK platform was conducted a few weeks after the bundle distribution. Of the 2340 farmers receiving their production input packages, 2041 could be tracked later in the season, resulting in a 87.2% completion rate (data not presented). Considering that the area was invaded by M23 rebels late in the cropping season, and travel was restricted following their occupation (that still continues), this level of participation is impressive. In this way, reporting through smart phones and tablets proved to be a valuable asset to the project (Byabuze *et al*., in press).

The yields of the different maize varieties examined within the technology bundles is presented in Table 2.

Table 2. Performance of the different bundled maize varieties.

Maize attribute	**WSC Haraka**	**WE5117**	**$PVA_{syn}13$**
Type	hybrid	hybrid	OPV
Mean (kg/ha)	5429	5347	2955
SEM	± 507	± 331	± 859
Locations (n)	8	7	2
Minimum (kg/ha)	3795	2854	1740
Maximum (kg/ha)	8034	5906	4170

The two maize hybrids (WSC Haraka and WE5117) substantially outperform the biofortified Open Pollinated Variety ($PVA_{syn}13$). In terms of their overall means, the hybrids performed very similarly but detailed comparison beyond this is risky as only WE5117 was planted in the adjacent highlands of Walungu, and direct comparison is available at relatively few (5) locations within the Ruzizi Plain. Where this comparison can be made, maize yields of 5574 ± 651 and 5347 ± 392 kg ha^{-1} were obtained for Haraka and WE5117, respectively, a difference that is too close to differentiate. We note that Haraka did provide over 8 MT per ha at the Luvungi location, outyielding WE5117 by over 2.4 MT per ha (44%). The overall result of the Season A outreach campaign is presented in Table 3. It is based upon the number or maize bundles distributed (2340), their coverage (0.25 ha each) and average maize yields of the three different bundled maize varieties (Table 2). This approach allows calculation of the total maize production by the campaign (2,660 MT) and a value for that production based upon a price of US $375 per ton (nearly $ one million). This approach does not consider what would have been produced by these farmers during Season A on these 585-ha using their current methods and without the coordination efforts under the service delivery model. Considering that yields of 2.1 MT ha^{-1} would likely have been obtained using minimal, farmer-available production inputs (Bagula *et al*., 2022; Bisimwa, 2023) suggests that the maize production increase is 1373 additional MT worth about $514,900 in existing local markets. Upon delivery, some of the production input packages were reportedly divided between farmers, but this does not affect this calculation. Summary outputs from the AALI Campaign Design and Analysis Utility appear in Table 4.

Table 3. Estimated total maize production by the different maize variety packages, their economic value (in US Dollars) and improvement over farmer conditions.

Maize bundle	Bundles (no)	Coverage (ha)	Maize yield (MT/ha)	Total maize (MT)	Maize value (US$)[a]	Improvement (%)
Haraka	509	127	5.429	689.5	258,556	147
WE5118	1032	258	5.347	1,379.5	517,322	148
PVA SYN14	799	200	2.955	591.0	221,625	41
Total	2340	585	4.548	2,660.0	997,503	111

Table 4. Summary outputs of the AALI Campaign Design and Analysis Utility initialized for the conditions described in this paper[1].

Summary parameter	Maize
Number of farms	2,340
Total coverage (ha)	585
Average farm investment ($/ha)	$317
Total costs ($)	$240,626
Average maize yield (kg/ha)	4,548
Farmer's Benefit:Cost ratio ($/$)	5.38
Total yield (t grain)	2,661
Overall grain value ($)	$997,718
Net return ($)	$757,092
Campaign Benefit:Cost ratio ($/$)	4.15
Total household beneficiaries (no)	15,210
Annual staple requirement (t/yr)	1,665
Staple food security (%)	160%

[1] Also assumes a 6.5 person hh, 0.3 kg staple/day

With bundle and coordination considered, total costs of the campaign were about $240,626 and provided a Total Net Return of $757,092 and an overall benefit to Cost Ratio of 4.15:1. This campaign exceeded the staple food requirements of its 15,210 beneficiaries by 60%.

Post-harvest mechanization, value addition and marketing services were planned but incompletely executed, largely due to the occupation by the M23 militia late in the growing season. Eight mechanization centers were established in the Ruzizi Plain during the 2025 Season A, providing access to petrol-powered maize shellers. These shellers provided service to 297 producers who recovered 45 tons of maize. Plans to transport the shellers to field locations could not be conducted due to conflict and restrictions place upon movement. Spraying services were also provided to 23 ha, mostly to control the Fall Armyworm (Cokola *et al*., 2021), but this was also less than planned.

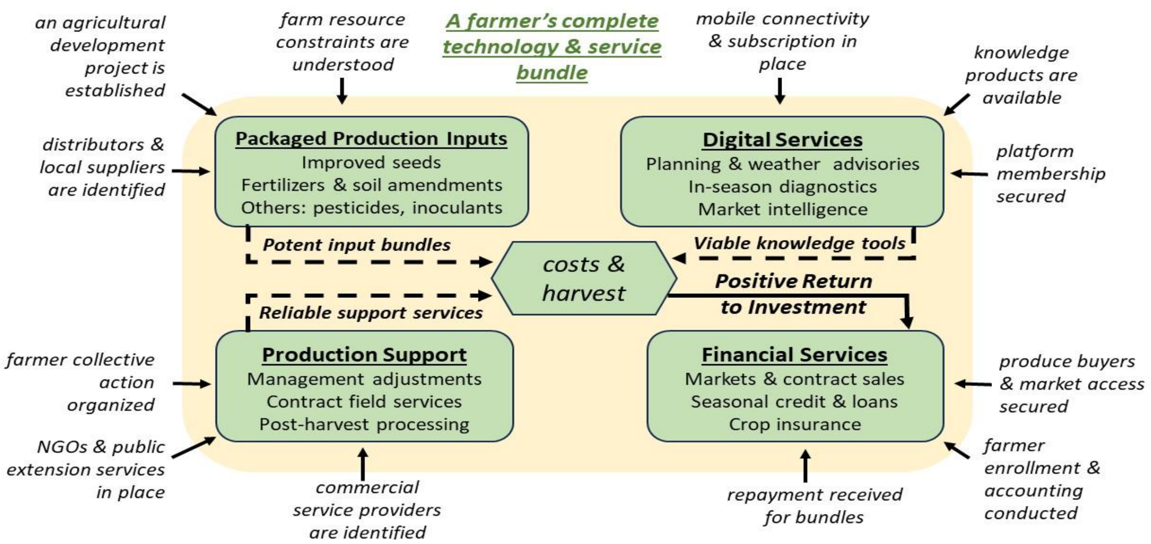

Figure 1. A conceptuel model of a four-component technology bundle and the driving factors related to those components that shape delivery models

Value was added to about 2.9 tons of maize received as in-kind repayment for the bundles through the milling of maize to commercial flour. While these efforts are relatively small compared to the outputs from the campaign itself, they represent a substantial "agri-preneureal" opportunities extended to youth and have demonstrated huge potential for project scaling under more normal, peaceful conditions.

Bundling is intended to improve upon the availability of key production inputs and the formulation and adoption of complementary services, resulting in a breakthrough in farmer practice and productivity. Bundling of accompanying inputs into a physical package for distribution to farmers with backstopping on- and off-farm services assists in the better design and understanding of projects, reinforcing agricultural transformation (Figure 1). Agricultural technology bundles are seen as having four basic, interacting components: Production Inputs, Management Support Services, Agricultural Knowledge Systems, and Financial and Marketing Support (Abetu *et al.*, 2024). Production Inputs are intended for use in stepwise, recommended ways and may consist of new crop varieties, mineral and organic fertilizers, and pest management products (Jayne and Sanchez, 2021). Management Support provides field and post-harvest services, particularly mechanization and first-stage agro-processing operations beyond the reach of individual farmers. Agricultural Knowledge Systems provide needed information along the entire value chain, including digital sources that offer weather prediction and warnings, real-time diagnoses of crop condition, and provide greater market intelligence (Ayim *et al.*, 2022). Marketing and Financial Support assumes the form of collective marketing advantages, value addition opportunities, and improved access to credit, vouchers and crop insurance (Mapanje *et al.*, 2023).

DISCUSSION

This season's outreach effort serves as a useful example of technology and service bundling (see Barrett *et al.*, 2020 ; Abetu *et al.*, 2024). First, a simple seed, fertilizer and instruction package was designed, assembled and distributed to small-scale farmers. At the time of delivery, training was provided in the installation of the technology package through the establishment of local field demonstrations. The campaign was conducted in conjunction with Provincial authorities and extension officers in a way that provides them with local ownership and recognition. Other services were provided as well, in particular the control of Fall Armyworm (Cokola *et al.*, 2021) and the availability of mechanized maize shellers. The introduction of hybrid maize to these farmers resulted in large yield increases (Table 2), and participating farmers were provided the option of marketing their maize surpluses to local processors through the campaign. They were also expected to repay the cost of their bundles through in-kind maize yield. This season's efforts serve as a second iteration of a combined agricultural problem-solving exercise in the Ruzizi Plain and surrounding highlands following our previous efforts described in Woomer *et al.*, (2024b). Our work in South Kivu illustrates how several barriers to modernized crop production may be confronted simultaneously through the design and release of technology and service bundles. In this case, bundling is viewed as a strategic practice of combining complementary technologies, practices, interventions, and services into a single package (see Agnew and Nakelse, 2024). We note that bundling of products and services has increasingly become a popular strategy for smallholder agricultural development in Africa (Barrett *et al.*, 2020; Abetu *et al.*, 2024; Woomer *et al.*, 2024b; Katungi *et al.*, 2025) and its introduction to DR Congo by the DRC Agricultural Transformation Agenda is a significant way forward. This assumes that government will further promote bundling of agricultural inputs and key services within its recently funded value chain and sustainable development initiatives, and that opportunities for value addition and access to markets will expand (see AfDB, 2024; CCP-PNAA, 2024; DRC, 2024). In this way, bundling serves as a catalyst for agricultural transformation, creating impacts across multiple rural development objective, particularly food security, but also increasing smallholder livelihoods, improving soil fertility, and promoting gender equality (Barrett *et al.*, 2020). Indirectly, the bundling may have an impact on peacebuilding as it will consolidate farmer groups driven by a common economic objective. This is built upon the assumption that offering a package of complementary technologies and services encourages farmers to adopt needed innovations, and stimulates the private sector to better provide these inputs, services and markets into the future.

The contents of Table 5 offer an overview of which bundle components are available through the current ATA-Ruzizi outreach campaign, and which are not. This analysis provides insight as to how our technology bundles may be further improved. The packaged production inputs are limited to improved seed, and pre-plant and top-dressed fertilizers. Earlier efforts addressing soybean included rhizobial inoculants and rock phosphate (agro-mineral) application, but are less relevant to maize cultivation. Note that many of the "missing" packaged materials are related to the promotion of organic matter recycling and soil health rather than the near-term alleviation of food insecurity. Management support services in this bundle are rather limited, but did provide farmers assistance in to control of insects (mostly Fall Armyworm) and mechanized shelling of their harvest. Many management options associated with more sustainable agricultural systems are not included within this bundle approach, but could guide additional extension agendas and bundling approaches in the future.

Similarly, our knowledge management approaches were rather incomplete, and do not yet extend into digital agriculture and smart phone advisories. AALI considers correcting this shortcoming as a priority for its ICT Department (see AALI, 2023). So too, our financial services are limited to marketing through collective action within the Farmer Training and Service Centers, value addition opportunity through the milling of maize flour and expectation of in-kind cost recovery, but do not yet consider improved credit and voucher access, crop insurance coverage and any form of adoption subsidy reward. Bundling builds on the idea that the whole is greater than the sum of its parts in the sense that bundles may have complementarities and multiplier effects, and these are increasingly realized within our cost-effective, multi-stakeholder outreach efforts in eastern DRC.

Table 5. Available and missing bundle components within the Ruzizi Outreach Campaign organized by category.

Production inputs

- ☑ Elite improved germplasm
- ☑ Mineral fertilizers (preplant formulations)
- ☑ Mineral fertilizers (top-dress formulations)
- ☑ Pesticides & application services
- ☒ External Organic Inputs: Compost & manure
- ☒ Nitrogen-fixing (or other) inoculants
- ☒ Lime & agro-mineral application
- ☒ Bio-fertilizer & Plant Growth Promoting Organisms

Management Support Services

- ☑ Labor-saving field mechanization
- ☑ Improved post-harvest mechanization access
- ☒ Crop residue retention & management
- ☒ Bio-control & Integrated Pest Management
- ☒ Irrigation & water management
- ☒ Alternative land preparation or planting schemes

Agricultural Knowledge Systems

- ☑ Extension "Good Agricultural Practice" support
- ☒ Weather advisories & Climate Information Systems
- ☒ Real-time crop diagnostics
- ☒ Market information & electronic sales & payment
- ☒ Field school instruction & internship

Marketing & Financial Support

- ☑ Collective marketing advantage
- ☑ Value addition opportunity
- ☑ Cost recovery provision
- ☒ Improved credit & voucher access
- ☒ Improved crop insurance access
- ☒ Adoption subsidy reward

Our four-component bundling framework presented in Figure 1 begins with the identification of yield-limiting constraints (farm resources), next assembles production inputs (upper left), best practices and essential services (lower left), and then considers investment and financial services (lower right). In a properly designed bundle, these inputs, practices and production support services result in greater and more marketable yields, and bring favorable outcomes for both those who purposefully bundle these products, and the farmers who deploy those bundles. Digital services occupy an increasingly important role in agricultural knowledge management (Tsan *et al.*, 2019; The Canopy Lab, 2024). Each of these four components have different drivers that are subject to management through program and policy interventions.

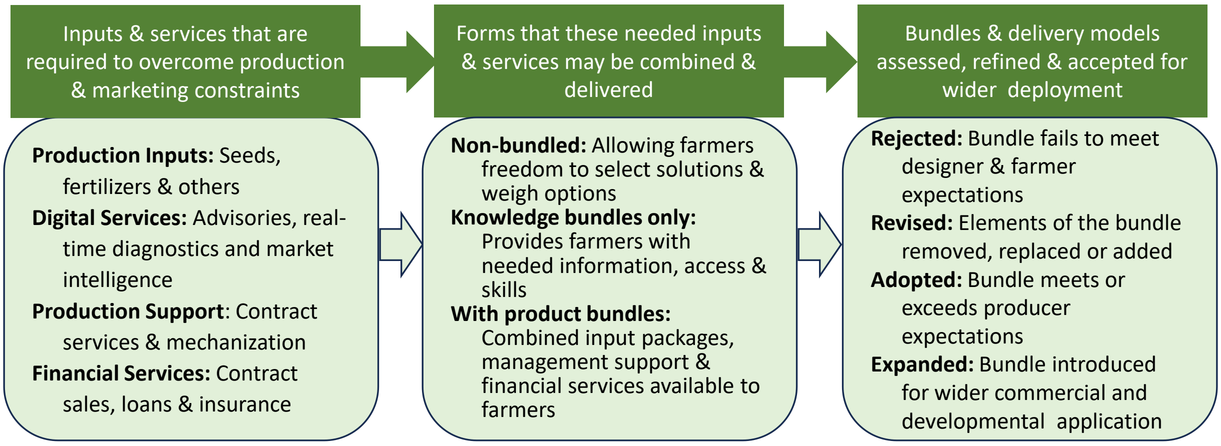

Figure 2. The process through which agricultural technology and service bundles are identified, composed and assessed

In the case of Digital Services, these include connectivity and subscription, posting current and reliable content, and access to farmer's platforms in the course of providing viable knowledge tools as related to planning advisories, in-season diagnostics and market intelligence and services. This is lacking in our current work within Ruzizi. However, access to potent production inputs, reinforced by other reliable support services, resulted in greater yields and profitable returns for the farmers investing their time and land in the bundles. These concepts frame how bundles are assessed and improved upon.

Figure 2 describes a process through which a bundling effort may be assessed and their formulation be accepted, revised or rejected. Where all the bundle components are readily available, the bundle itself may be exercised through the investment and management decisions of individual farmers. This forms the basis of the conventional "business-to-farmer" delivery model, often in conjunction with public agricultural extension. In this way, these farmers remain "unbundled", with freedom to select solutions and weigh guided options (Figure 2). Also represented in Figure 2 is the "knowledge-is-power ICT-led" model that leverages a wide array of digital technologies to provide commercially-oriented services such as planning advisories, in-season diagnostics, market access, and financial connection, but not the physical production input packages themselves. But where more formalized and complete technology bundles are deemed necessary to stimulate rural economic growth, bundles may become less reliant on Knowledge Systems, particularly digital applications, and assume a more balanced, backstopping presence. Knowledge Systems have potential to advise farmers on the best course of action, including which inputs to apply and where to seek management support and financial services (Tsan *et al.*, 2019); but in the case of more balanced and cohesive packages, such as a "government-to-platform-to-farmer" delivery model described in this paper, production inputs are provided under some mutually agreed terms in the expectation of greatly improved yield. This goal is then reinforced through information campaigns and service mechanisms that buttress successful farming outcomes. These more cohesive bundles may require "tweeking" adjustment to different agro-ecological and socio-economic conditions, but not in ways that confuse or alienate their intended beneficiaries, so we strive to "keep bundles simple but potent".

Bundles become more attractive when linked to market mechanisms that ensure surpluses are readily sold at reasonable prices. Ultimately, the bundles themselves may be marketed to farmers and they become customers to all or some of the offered products and services. This later outcome requires more comprehensive approaches that include organizing farmers into cooperatives, developing commercial distribution channels, and training agro-dealers and sales agents. Overall, the value of a bundle is measured in its growing popularity and its ability to overcome historic food insecurity and service provision gaps.

Strengthening our future partnership with AgriForce Ltd. is another important opportunity emerging from this work. AgriForce started producing hybrid maize seeds in 2023 and provided the WE5117 seed used in this campaign (see Tables 2 and 3). This operation marked the beginning of commercial production of hybrid maize seeds in South Kivu, a major step forward toward the development of seed systems, an effort assisted by IITA and the Seed Systems Group. These seeds were further popularized through this outreach campaign and performed very well (Table 2). AgriForce is based in Bukavu, South Kivu, an area that remains under M23 occupation and curfew, but the company has maintained its hybrid parent material and is expected to rebound when the current political and military situation is resolved.

As a limitation to this work, the Ruzizi Plain has been the area of recent conflict with the M23 militia taking over large parts of north and South Kivu since January 2025 (Hatem *et al.*, 2025). We note with concern that the southernmost front line of the M23 rebels currently runs through the northern part Ruzizi Plain, and across the domain of the ATA-DRC Kivu outreach campaign presented in this paper. Battles were fought during the outreach work in February 2025, but "lines of control" were later stabilized. Control of the Ruzizi Plain is strategically important because it borders between DRC, Burundi and Rwanda and provides a valuable agro-industrial corridor. Our outreach campaign was forced to continue its operations under this difficult and dangerous situation; and due in part to its reliance upon digital devices, proved resilient in some unexpected ways (Byabuze *et al.* in press).

CONCLUSIONS

Despite the compromising geo-political tension in the region. the second iteration of our Ruzizi Maize Outreach Campaign performed well in terms of its stakeholder reach, sizable contribution to food security and overall support to the area's maize value chain. It also contributed to increased cohesion among smallholder farmers and provided the tools to youth and women that allows agriculture to better serve as the engine for economic growth and food security. This season's efforts were better linked to current developments in the design and implementation of bundled technologies and services, and additional effort addressed the needs for contract field and post-harvest services. It is expected that continued effort along these lines will result in better bundling and outreach capacities into the future (Barrett *et al.* 2020; Abetu *et al.*, 2024). Season-ending operations were conducted under extremely difficult and sometimes dangerous field conditions, as the outreach domain was contested by armed conflict, and this limited the reach of our planned services to the farming community and local entrepreneurs. Future efforts must also better consider digital information services and linking participating farmers and private sector partners to stronger commercial financial and marketing services in ways they can appreciate and afford (Ayim *et al.*, 2022).

In the future, the AALI-IITA consortium working with and through the Government must further promote higher-performance maize varieties and better address more site-specific soil conditions. We must improve training on the early identification and integrated management of pests and diseases before they cause major economic damage. We shall improve our logistics and monitoring and evaluation capacities, and better account for climate adaptation, particularly as it relates to heavy precipitation on sloped lands and general soil health. The current political and military situation requires that we better collaborate with local communities to improve the security of project activities and safety of beneficiaries in conflict-prone areas (Chilunjika, 2024). We conclude that food security initiatives must not be weaponized (see Olaniyi, 2025) because the poorest and most vulnerable must continue to eat healthy foods throughout human-induced turmoil beyond their control, and all those seeking to modernize smallholder agriculture and support its value chains should be respected and feel protected in their endeavors.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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