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Knowledge management for innovation in agri-food systems: a conceptual framework

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ABSTRACT
Knowledge is a critical enabling factor for healthy agri-food innovation systems (AIS). AIS and related knowledge management (KM) frameworks face significant implementation challenges. We review applications of KM to AIS, the current state of the art and shortcomings and present a new KM framework, Agricultural Knowledge Management for Innovation (AKM4I). Previous agricultural KM frameworks do not integrate innovation pragmatically, use linear, reductionist, top-down pathways to innovation, and do not explicitly incorporate issues of power, politics, ownership, and trust when combining scientific and local knowledge across multiple stakeholders. The AKM4I framework addresses systemic interactions favouring innovation outcomes by formalising flows and management of information and knowledge between diverse sets of stakeholders; and explicitly considering previously unresolved practical and relational barriers aiming to facilitate more equitable, rapidly evolving, and actionable knowledge generation and management for innovation and transformational change. An agricultural case study serves as an example of the implementation of AKM4I.

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1. Introduction

Over 2 billion more people will need to be fed with balanced and healthy diets by mid-century and substantial dietary shifts will be needed to improve both human health and environmental sustainability (Willett et al., 2019). Climate change, urbanisation, and changing intensifying patterns will further increase the pressure on our productive ecosystems (Lobell et al., 2008). Human nutritional security is driven by complex and dynamic systems that interact with agriculture and food production, distribution, economic and physical access, consumption, health, and environmental issues, and affect the stability and sustainability of the food supply and of nutrition itself (Hammond & Dubé, 2012).

This paper provides a systemic conceptualisation to illuminate functional elements of complexity in agri-food system processes and applications of Knowledge Management (KM) to meet agricultural and innovation goals. It builds on existing frameworks and integrates historical agricultural KM strategies while facilitating the targeting of locally adapted technology, constructive and collaborative knowledge sharing for innovation. The proposed Agricultural Knowledge Management for Innovation (AKM4I) framework intends to i) recognise that agri-food systems are complex adaptive systems, and that KM must reflect this complexity; ii) support the integration of explicit, implicit, and tacit knowledge through process-oriented "knowledge in action"; iii) lay the foundation for reciprocal and collaborative relationships amongst diverse stakeholders; iv) incorporate context specificity in agri-food systems across sites, actors, and processes; v) address the importance of communication channels for knowledge and innovation; vi) move beyond traditional monitoring and evaluation to incorporate accountability and learning; vii) account for potentially obstructive power dynamics and knowledge ownership challenges; and viii) create opportunities to integrate KM with decision-support systems and tools, for the benefit of all stakeholders in the agri-food systems.

1.1. Complex agri-food systems

Complex systems share certain properties, including: i) individuality, where systems are multilevel but usually driven by the decentralised interaction of constituent individual parts; ii) heterogeneity, expressed in substantial diversity among actors; iii) interdependence among pieces and across different levels and subsystems; iv) emergent phenomena – patterns that form in the system which may be difficult to predict from each individual element; and, v) nonlinearity and tipping points, where impacts caused by small changes can seem hugely out of proportion, or that the system

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may spend long periods in a state of relative stability, yet be easily "tipped" to another state by a disturbance that pushes it across a threshold (Hammond, 2009). These foundations of systems theory are flexible enough for integrating related systems and networks, thus facilitating conceptual synergies across modes of knowledge (Carayannis et al., 2016).

Agri-food systems are an example of a planetary-scale complex adaptive system as they are composed of many heterogeneous pieces interacting in nonlinear ways that strongly influence overall outcomes (Hammond, 2009). They operate at a range of temporal and spatial scales and are comprised of complex interconnections, which complicates the task of achieving synergistically positive developments across multiple priorities (Whitfield et al., 2015). Meeting humanity's current and future nutritional needs via food production and distribution, while simultaneously ensuring long-term environmental and economic sustainability along with human health and social equity is a "grand systemic challenge" (Horton et al., 2017). While the term "sustainability" has eluded an adequate functional definition, there is general agreement that the goal is to steer food production and distribution systems to fully meet humanity's present needs and other requirements indefinitely. A sustainability space for any given system has n-dimensions defined by the multitude of social and ecological boundaries that represent the limits of acceptable conditions for a system. Hence, sustainability can also be defined as a measure of the extent to which systemic changes, over time, move components of the system within or beyond the limits of a non-static sustainability space (Whitfield et al., 2015).

1.2. Agricultural knowledge management (AKM): current state of the art

Knowledge consists of experience, attitudes, values, skills, contextual information, and expert insight that enables to function in a coherent, systematic, and effective manner; it can be explicit, when formal; tacit, when has been internalised from trial and error, reflection or review or implicit, when it is intangible. These knowledge classifications operate on a continuum and distinctive interactions have been identified: i) socialisation (tacit knowledge is shared through experiences); ii) externalisation (tacit knowledge is converted to explicit using metaphors and analogies); iii) combination (explicit knowledge is systemised and refined); and iv) internalisation (explicit knowledge is transferred to tacit translating theory into practice)(Grant, 2007; Lwoga et al., 2010). Knowledge-intensive systems and processes require comprehensive approaches and the distinction between tacit and explicit is insufficient (Jashapara, 2007; McInerney, 2002).

Knowledge is a critical enabling factor for healthy agri-food systems, and is required to generate contextual information and processes to improve productivity, increase profitability, reliability and resilience (Qaim, 2017). Deficient knowledge may result in poor production, decreased stability and flexibility, and harm to natural resources (Babu & Blom, 2014; Hui et al., 2014; Morgan & Murdoch, 2000) as well as producing agricultural products that do not meet consumers' demands (e.g., quality). Likewise, interventions that do not take into consideration the complete knowledge landscape are unlikely to achieve the desired outcome and may result in unintended consequences (Cash et al., 2003).

Multiple frameworks have been introduced to explain and analyse different types of knowledge generation and transfer in agricultural systems (Table 1). It is increasingly recognised that knowledge cannot be transferred from one "reservoir" to another in complex agricultural contexts, and that the purpose of a knowledge system is not naturally or scientifically determined; instead, it is understood as an emergent property, interactively shared and developed by the stakeholders themselves (Kummer et al., 2010). Knowledge boundaries, attributes for knowledge sharing, situated learning within communities of practice for knowledge brokering and integration, Information and Communication Technologies (ICT) and knowledge systems, innovation platforms and networks are some of the KM strategies proposed by these frameworks. Some of them characterise the knowledge flow as cyclical processes, others study the linear perspective (e.g., value chain), and some others focus on the learning networks.

However, neither framework accounts for the complexity of agri-food systems and the role of KM in understanding and intervening its dynamics (including boundaries, layers, heterogeneities, subsystems, interdependencies, and reciprocal relationships), or advancing beyond the knowledge sharing and technology transfer perspective to consider systemic change and innovation processes. In order to face the current food-related challenges, including ever-stronger imperatives for social equity and environmental sustainability, more efficient knowledge management must take place.

1.3. Innovation in agri-food systems

There are varied opinions on how best to leverage knowledge to boost innovation in agri-food systems, ranging from focusing on improving technology adoption to more accurately parameterising scientific models, to creating novel bottom-up innovation pathways that reverse traditional largely top-down research-for-development modes (Girard, 2015).

Table 1. Agricultural Knowledge Management frameworks (adapted from Ali and Advic (2015).

Frameworks	Purpose/Objective	Type of Knowledge	KM Strategies	Knowledge beneficiary
Boshkoska et al. (2018)	Development of a DSS: decisionsupport system in order to evaluate the knowledge boundaries in agricultural value chains.	Tacit and explicit	DSS to identify knowledge boundaries and attributes for knowledge sharing	Value chain key actors
Alemu et al. (2018)	Integrate scientific and indigenous knowledge through agricultural KM system development for K sharing and integration.	Scientific and indigenous knowledge	Extension agents as knowledge brokers; informal and formal networks; knowledge translation.	Farmers and value chain actors
Vangala et al. (2015)	Codify and share tacit knowledge, create new knowledge and involve key stakeholders in the KM process of Indian agricultural organisations	Tacit and explicit from farm communities and agricultural organisations	Web Portals, ICT & Intermediator/ Knowledge workers and mobile technology/ telephone	Farmers and local community
Howland et al. (2015)	Understand attitudes, skills, and practices of fruit growers and define the necessary conditions for effective information sharing.	Tacit and explicit knowledge on fruit production	Knowledge-sharing online platform	Fruit farmers in Colombia
Lwoga et al. (2010)	Managing and integrating indigenous and exogenous knowledge for improved farming activities in Tanzania	Indigenous and exogenous	Face-to-face communication, public and private extension services, telecentres	Rural communities, farms in Tanzania
Meijer et al. (2015)	Analytical framework combining extrinsic and intrinsic factors in farmers' decisions to adopt new agricultural technologies	Explicit (technologies) and tacit (perceptions and attitudes)	Decision-making framework; extension services	Smallholder farmers in sub-Saharan Africa
Linger et al. (2013)	Describes an action-oriented Task-based KM framework aimed specifically at building capability for policy work in sustainable development	Explicit (science) and tacit (tradition, social norms, local lore)	Consolidation of diverse information streams; means to build a shared understanding of problems	Sustainable development stakeholders in Indonesia
Hess (2006)	Rural development networks for knowledge sharing	Tacit (indigenous knowledge found in local rural areas) and explicit (outside world knowledge)	Mobile phone, email, radio, video	Local/rural community, donor agencies
Rahaman (2004)	Comparison of concepts, approaches and methodologies, useful for harnessing traditional knowledge (TK)	Tacit (traditional) and explicit (scientific)	DSS for ensuring access, benefit sharing and documentation of TK	Local community researchers

The Agri-food Innovation System (AIS) framework is becoming increasingly popular, furthering the transition from the development and linear transfer of technologies by experts towards system-aware approaches based upon processes of integrated problem analysis, participatory priority setting, and co-designing and implementing technological and socio-organisational solutions by diverse stakeholder networks (Camacho-Villa et al., 2016; Klerkx et al., 2012; Reynolds et al., 2017; Schut et al., 2016).

An AIS is a web of dynamic interactions among researchers, input suppliers, extension agents, farmers, traders, and processors engaged in the creation, diffusion, adaptation, and use of knowledge relevant to agricultural production and marketing (Hellin & Camacho, 2017). The drivers of AIS extend far beyond research (Klerkx et al., 2012). In AIS, innovation functions as a process where farmers' and rural entrepreneurs' knowledge, motivations, and values play a very important role (Knickel et al., 2009). Innovation emerges from complex sets of interactions among multiple actors by collaboratively identifying, analysing problems and researching, designing, testing, and implementing strategies to improve outcomes and foster technical, social and institutional change (Klerkx et al., 2012; Schut et al., 2016). Klerkx et al. (2012) conclude that an efficient way to perform innovation brokering is through KM – generating linkages and facilitating functional innovation pathways, and dissolving barriers between research, policy, and practice in ways that allow for and encourage feedback loops.

Innovation is an emergent phenomenon in a complex system and results from non-linear and iterative processes, which require consistent metamorphosis and adaptive management; this reality of AIS can cause tension with inflexible, linear frameworks (Kilelu et al., 2014) such as those generally applied to KM in agri-food systems.

2. The AKM4I framework for innovation in agri-food systems

Extant AKM frameworks have predominantly focused on KM processes within specific targets, which does not necessarily encompass reciprocal interactions among several stakeholders, nor explain what outcomes or innovation processes (if any) occur upon knowledge generation and transfer. To extend beyond these historical barriers, we propose a new framework

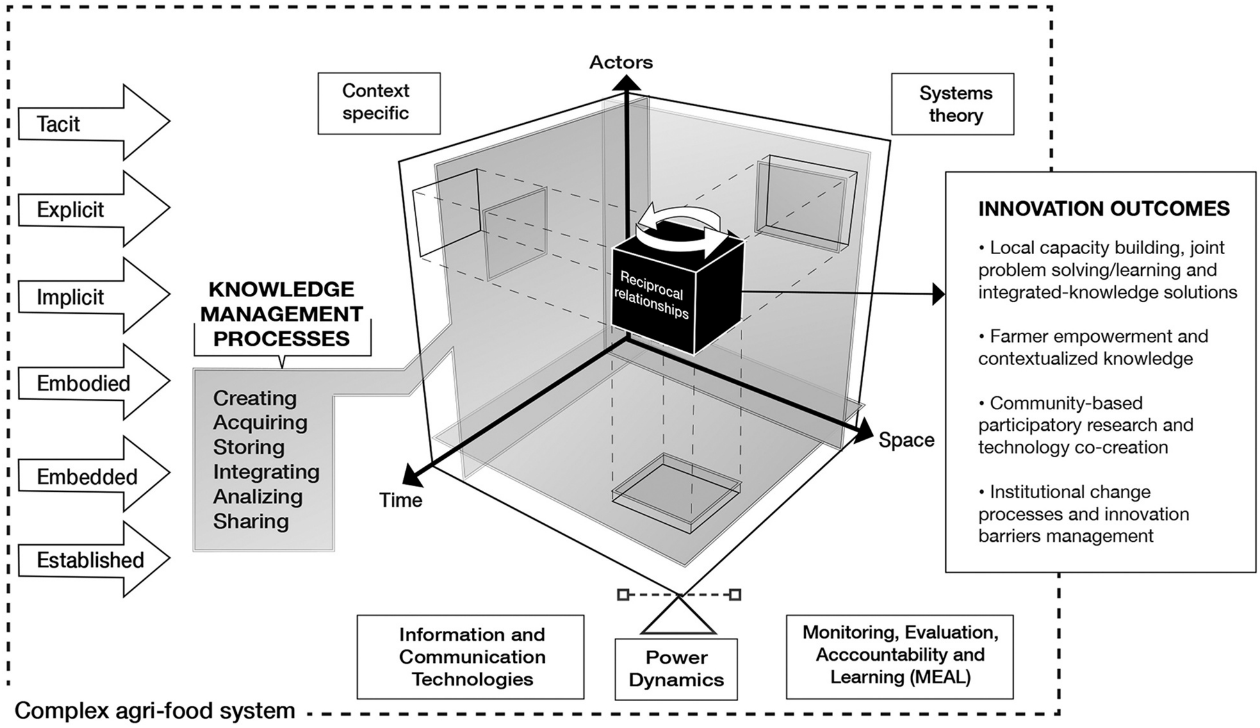

Figure 1. AKM framework for Innovation (AKM4I) in agri-food systems.

(AKM4I) for enabling innovation and pursuing sustainability (Figure 1).

2.1. AKM4I framework principles

2.1.1. Application of systems theory and integration of knowledge types

Fostering innovation for sustainability in agri-food systems entails unpacking functional system dynamics to answer concrete questions regarding what is to be sustained, where, at what scales, how, for whom and trade-offs in each case. Applying the logic of complex systems allows speaking of multi-level processes of knowledge and/or innovation, which could accurately guide decision-making processes to answer such questions. Carayannis et al. (2016) present "Mode 3" to address this complexity by conceptualising a multilateral, multi-nodal, multi-modal, and multi-level systems approach that aims to enable self-organised knowledge generation, collaborative processes for co-design and co-implementation, context focused outcomes, and processes driven not only by scientific individuals (Carayannis et al., 2016). Based on these principles, "Mode 3" could lead to a more equitable, rapidly evolving, and actionable knowledge generation. Another way to address a complex knowledge system is through a many-models approach, which allows analysing a high-dimensional object with multiple lenses (Page, 2018). Since systems theory intends to explain human behaviour as the intersection of the influences of multiple interrelated systems, applying its frameworks to AKM could help to identify tipping points for innovation, unintended outcomes, impact pathways and even performance indicators of the system.

2.1.2. Reciprocal relations, power, and political dynamics of AKM

Rather than top-down linear exchange between researchers and farmers, agri-food systems require knowledge transfer across all players to ensure equity and democratisation of knowledge processes. AKM must consider whether agricultural research is meeting specific local needs, if peer knowledge sharing is a positive cost/benefit relation and how information is flowing back and forth among farmers, extension systems, governments, private sector and other actors. A key challenge for agricultural researchers is to move away from an overtly research-centric approach, as this is likely to perpetuate "the conventional divide between agricultural research and extension" (Pant, 2012, p. 125).

The use and creation of knowledge in system processes requires political dynamics embedded in a complex social landscape (Ferguson et al., 2010) that can both hinder and advance the benefits of KM. For instance, several studies suggest that knowledge networks initiated by decision makers or experts can be used to legitimise specific policy interests, which can lead to the overlooking of the knowledge of some actors and undesirable outcomes (Ferguson et al., 2010). Further, the notion of knowledge as an extractable resource can crowd out tacit and implicit knowledge assets that are difficult to formalise, and can result in farmer exclusion from both information and resources (Srang-iam, 2013). Power and knowledge are deeply interrelated (Foucault, 1980). The presented framework extends upon the post-rationalist approach to KM for development presented in Ferguson et al. (2010), which recognises the situated and practiced-based nature of knowledge embedded within social relationships.

2.1.3. Context-specific agricultural knowledge for sites, actors and processes

Farmers make decisions within the context of their complex realities and production systems. In the past, when confronted with the tension between farmers' realities and practical action, professionals opted for "simplicity", which is often manifested by mono-disciplinary recommendations that are not relevant to the multi-faceted problems that farmers face (Chambers, 1993).

Site-specific information allows farmers to take charge of many aspects of production that previously were assumed to be random acts of chance, or subject to overly generalised recommendation domains of extension agents (Jiménez et al., 2016). Further, field-scale observations and demonstrations have little use for other farms if site-specific differences are not incorporated. This process enhances the value of farmer observations and tacit knowledge obtained from an applied agricultural setting, so that the observations and experiences of farmers create an improved and more actionable knowledge base to inform locally adapted farmer decisions across a diversity of conditions.

Context specificity of AKM must also include actor and process variability. Actors include, but are not limited to, farmers, extension agents, local data analysts, NGOs, governments, and donors; value chain processes to be considered range from research, production, policy making, industrialisation, commercialisation, and consumption; political dynamics must incorporate power differentials between and across stakeholder relationships.

2.1.4. ICTs and channels for decision-support systems (DSS)

KM for agricultural systems can leverage ICT advances to facilitate a continuous exchange of knowledge generation processes, localised practices, collective needs, and research results across farmers, development experts, scientists, citizens, and policy makers (Hartwich et al., 2007). ICTs can also systematically place data analytics at the forefront of decision-making (Hilbert, 2016). Data mining techniques allow extracting embedded knowledge associated with farmer experiences from large observational datasets to identify best practices (Delerce et al., 2016). Big data, observational research, crowdsourcing, data mining, machine learning, distributed databases, biotechnical agri-food systems and technology-driven local markets are some of the new options available to foster knowledge revolution in agriculture (Poppe et al., 2015; Wolfert et al., 2017). KM can translate knowledge into data to feed decisions support systems (Hoogenboom et al., 2004) or precision agriculture tools (Lindblom et al., 2017). However, the digital divide and data challenges are still present, ranging from heterogeneity, inconsistency, incompleteness, and privacy concerns to difficulties in visualisation and collaboration (Jagadish et al., 2014).

Communication channels distribute information not only for diffusion of results, but also to increase the potential for change in complex settings (Leeuwis & Aarts, 2011). Facilitators, knowledge brokers, and communication tools play increasingly important intermediary roles among stakeholders in KM (Leeuwis & Aarts, 2011) and crucially allow feedback mechanisms. If knowledge is generated but not communicated properly, and there are no mechanisms for feedback and evolution of knowledge, then the knowledge production cycle is likely to stagnate. Further, creativity and innovation increase with the diversity of the members in a system, and the levels of learning and adaptation augment with the density of communication within the system (Hartwich et al., 2007).

2.1.5. Monitoring, evaluation, accountability and learning (MEAL) for complex systems

The digital revolution also incentivises the evolution of monitoring and evaluation systems that are now able to gather, organise and analyse vast amounts of data. However, big data does very little without proper understanding and interpretation. Additionally, empirical data can be misleading: social, economic and political environments are not stationary, and without logical models people tend to overweight recent events, assign probabilities based on reasonableness, and ignore base rates (Page, 2018). Furthermore, traditional MEAL systems in AIS are not understood as knowledge management systems so far, and they still tend to measure linear indicators mainly related to increased production and productivity with little attention to institutional, environmental, contextual and social issues, i.e., systemic questions.

Therefore, the main objective of any MEAL system in agriculture should be to incorporate the latest research and technology regarding modelling, monitoring and understanding complex systems to be able to identify performance indicators, nodes, layers, tipping points, and unintended outcomes over time through observational data. This will support decision-making processes intending to achieve optimal farming systems of improved productivity, minimal use of resources and impact to the environment. Organised data also serves donor purposes for accountability, transparency and traceability for value chain integration.

2.2. AKM4I framework processes

Figure 1 introduces the primary processes within the proposed AKM4I framework, integrating the eight AKM4I principles with key concepts required to facilitate innovation in agri-food systems. The process elements of the framework are explained below.

2.2.1. Creating, acquiring, and storing knowledge

Knowledge creation, essential in the innovation process, is considered here to be the formation of new ideas through interactions between explicit, implicit, and tacit knowledge, which may extend beyond a single individual (Von Krogh et al., 2011). The relationship among different actors is fundamental to the creation and acquisition of knowledge, as it allows an exchange of questions, needs, practices, research methods, and research findings. Such interaction also favours the transmission of tacit and implicit knowledge and peer-to-peer learning, which require relationships of trust among actors (Smith, 2001; Topping, 2005). ICT enable a KM approach to gather, store and organise larger data sets in shorter periods, at a lower cost, and can favour the creation of explicit knowledge that easily can be integrated into innovation processes (Mahr & Lievens, 2012).

2.2.2. Integrating knowledge

Knowledge integration has three principal purposes: illustration, convergent validation (triangulation), and the development of analytic density, or "richness" (Fielding, 2012). Appropriate data integration methods within AKM support the creation and acquisition of knowledge by matching data from qualitative and quantitative methods, by uncovering new knowledge in large existing datasets through data mining techniques, and by synthesising diverse data sources at different levels (farm, field or landscape; Horton et al., 2017). In principle, data integration can improve the combination of tacit and explicit knowledge, systematising the interactions between research and extension communities, and articulating knowledge from different sources for a certain site, actor or process. Trusted and transparent ICT solutions are essential to address different approaches to data and knowledge prioritisation across actors and potential issues of incommensurability and interoperability. Despite these challenges, data integration provides a critical step towards making diverse sources of knowledge explicitly accessible and useful to all agri-food system agents.

2.2.3. Analysing knowledge

Analysis has been defined as the process of inspecting, cleaning, transforming, and modelling data with the goal of discovering useful information, suggesting conclusions, and supporting decision-making. Data analysis can be broadly classified into five types, presented in Figure 2. In descriptive analytics, data collected in the field will be processed through comparisons to generate patterns and trends during diagnostics. Inferential analytics explore mechanistic relationships at a variety of scales, which underpin innovation processes to solve agri-food system problems and quantifies whether an observed pattern will likely hold beyond the data set at hand. Predictive analytics allows for modelling the future, showing the possibility to predict one measurement

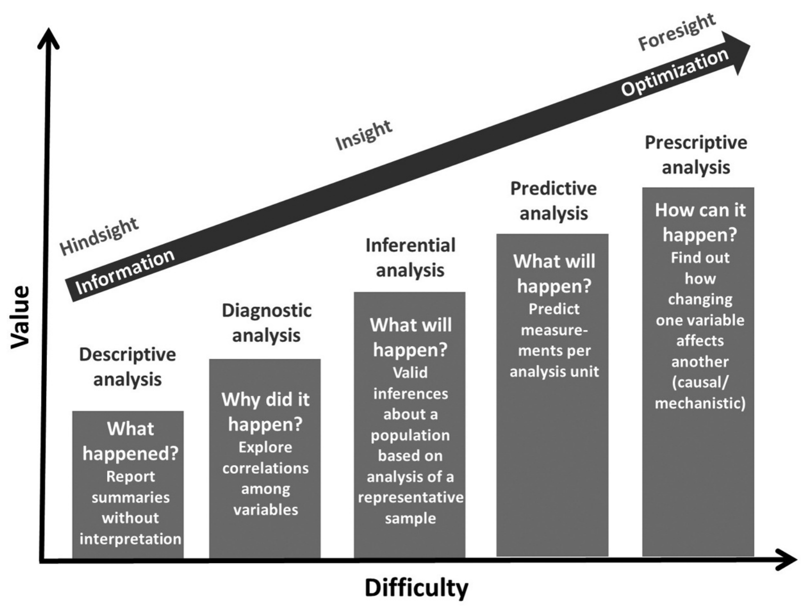

Figure 2. Types of analysis (adapted from Leek and Peng (2015) and Elliott (2013)).

from another yet not necessarily explaining why that choice of prediction works, while prescriptive analytics can kick-start the creation of models to support decision-making processes – generating the capacity to suggest concrete actions from the data collected. Methodologies for analysing agricultural data should generate all five analytical levels, from the description of information to the optimisation of predictive data.

Since data is increasingly available, new methods to organise and interpret it, to understand complex phenomena should be considered. For instance, a many-model thinking approach allows the application of ensembles of models to make sense of complex phenomena (Page, 2018).

2.2.4. Sharing knowledge

Recent research on alternative approaches has focused on knowledge sharing across heterogeneous actors, rather than linear knowledge transfer (Wood et al., 2014). When successfully implemented, knowledge sharing can influence and shape skills, attitudes, and activities of personnel in achieving organisational goals (Collins & Clark, 2003). Sharing can be done directly via personal communication or indirectly using an intermediary tool (Bock et al., 2005), yet is also mediated by social behaviours and power dynamics. In the case of AIS, a recent study found that a lack of funds, horizontal and vertical fragmentation within organisations, and a lack of proper evaluation criteria for collaborative innovation networks are among the key threats to collaboration and social learning (Hermans et al., 2015).

2.3. Knowledge innovation pathway

Table 2 summarises the innovation pathway facilitated by AKM4I principles and processes, illustrating the linkages between the features of complex agri-food systems and ultimate innovation goals. The characteristics of complex agri-food systems, including individuality, heterogeneity, interdependence, emergence, and tipping points, all have major ramifications for how knowledge must arise and flow to promote innovation. Each characteristic was a driver for the structure of the AKM4I framework, which intends to translate system complexity into innovation outcomes.

Any innovation path should begin by considering individual-level learning and decision-making processes, as decisions about what to buy, what to eat, what to produce, and what to prioritise have significant ramifications for the balance of an agri-food system (Hammond & Dubé, 2012). In addition, MEAL and ICTs should be present in as many relationships and interactions as possible to allow a continuous evaluation of the systemic process and adequately communicate in each case. Power dynamics are essential to consider in all steps and in all relationships, as outlined above, which, combined

Table 2. Innovation outcomes generated through AKM4I embedded in complex agri-food system (based on Hammond (2009), Hammond and Dubé (2012), and Schut et al. (2016)).

Complex Food Systems Properties	AKM4I Principles	Innovation Outcome
INDIVIDUALITY: Driven by decentralised interaction of constituent parts. Each level is composed of autonomous actors who adapt their behaviour individually.	K INTEGRATION: Information flows between tacit, implicit, and explicit K are a starting point for innovation.	• Integrated solutions to agricultural problems through different types of knowledge and clear communication channels • Joint problem solving and learning across a-f system • Local capacity building, farmer empowerment
HETEROGENEITY: Substantial diversity among actors at each level – in goals, rules, adaptive repertoire, and constraints – can shape dynamics of the system.	CONTEXT-SPECIFIC: Site-specific information allows farmers to control aspects of production that previously were assumed to be random acts. It must also consider actor, process, and political differences.	• Contextualised agricultural knowledge, research and technology • Foundations for farmer empowerment in their local environment
INTERDEPENDENCE: Contain interdependent pieces, interacting across levels. System dynamics are often characterised by feedback and nonlinearity.	RECIPROCAL RELANTIONSHIPS: Rather than top-down linear exchange, mutually beneficial K transfer across levels must occur. Considers research meeting local needs, and how and why knowledge is flowing back and forth between actors and levels.	• Community-based participatory research, information sharing and learning • Farmer involvement in contextualised technology development • Foundation for restructuring power dynamics
EMERGENCE: Unexpected phenomena – patterns of collective behaviour difficult to predict from separate understanding of elements.	POWER DYNAMICS: Adaptive communication and management allows iterative, flexible innovation and addresses roles hierarchies & expectations for partners.	• Addressing structural power inequalities between stake-holders across different levels • Institutional change processes • Addresses key innovation barrier head-on
NONLINEARITY & TIPPING: Nonlinear impacts caused by small changes can seem hugely out of proportion. The system may spend long periods in a state of relative stability, yet be easily "tipped" to another state by a disturbance that pushes it across a threshold.	K SYSTEMS FRAMEWORKS Reciprocal relationships within *Mode 3* of K production, specifically considering systemic risks, stability, resilience, and efficiency	• Enhance systems capacity to generate and respond to change and innovation capacity in the system • Understand innovation as a process of technological and non-technological changes

with communication channels and ICT tools, promote generation and flow of information for adapting to emergent and interdependent processes of complex systems.

3. Case study: the AKM4I framework in CIMMYT

3.1. The hub concept and its results in Mexico

Over the past decade, the International Maize and Wheat Improvement Center (CIMMYT) has been working on innovation in agri-food systems, specifically in maize- and wheat-based systems in Mexico. The innovation work is organised in agro-ecologically distinct hubs; each hub has a physical infrastructure, including research platforms, modules, extension and impact areas, which are used for networking, knowledge exchange and co-creation (Figure 3). In the research platforms, local partners evaluate technologies and local tacit knowledge to develop research-based recommendations for farmers. In modules, farmers are connected to peers, farm advisors and other value chain actors. Together they implement and adapt best practices from research platforms and compare them with conventional practices. Extension areas are agricultural fields where farmers test new technologies in connection with modules or research platforms, whereas in impact areas farmers have adapted and adopted similar knowledge, technologies and innovations on their own (Figure 3).

This infrastructure is used to build a network of stakeholders – farmers, farm advisors, scientists, research centres, private initiative, and government actors, among others – that collaborate around a common objective: innovation in the agri-food system to make it more sustainable, productive, profitable and resilient. The hub model considers farmers important change agents and central to the approach. Since inception, hubs have been allowed to evolve independently in order to match their divergent agricultural, stakeholder, and technological contexts, and to reflect the landscape of relationships between different actors in the agri-food system (Camacho-Villa et al., 2016).

The work is funded through partnerships with several actors, of which the Government of Mexico has been the largest funder, both at the federal level through the Ministry of Agriculture and at the state level in Guanajuato, a state in the central highlands. Additionally, several private foundations have supported hubs in different locations. Recently,

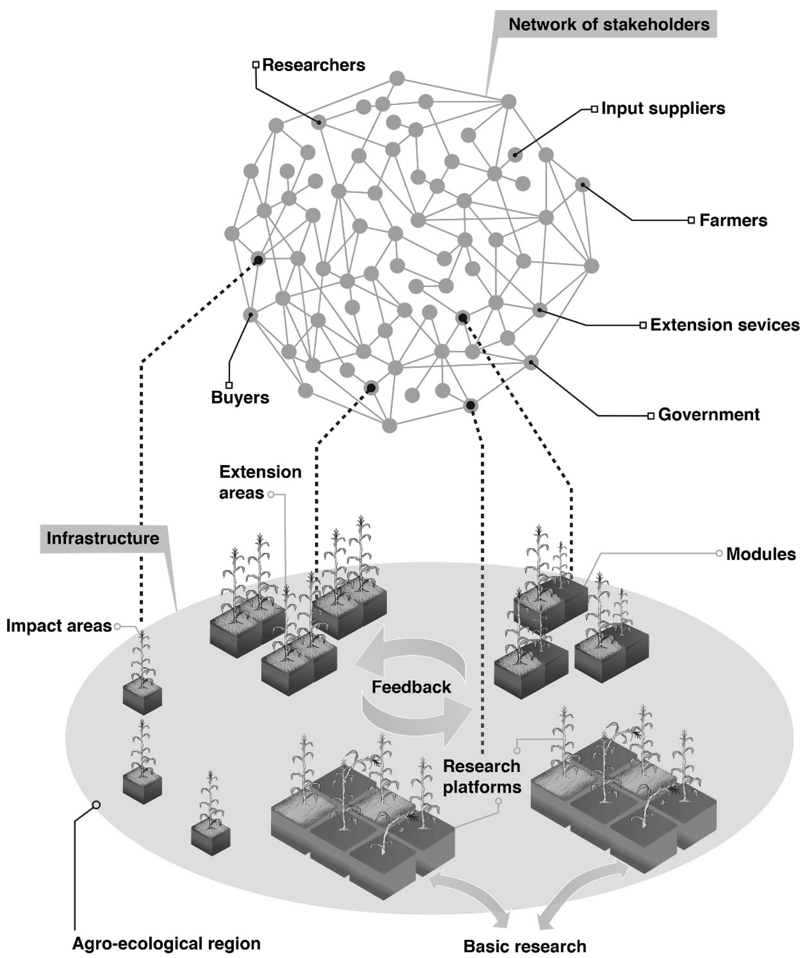

Figure 3. A schematic illustration of CIMMYT hubs.

companies looking to increase sustainable, local sourcing options for maize and wheat have partnered with CIMMYT in several hubs, to generate a pull-effect for sustainably produced grain and help farmers to improve their access to markets to trade increased production volumes.

In 2018, 12 hubs were operational in Mexico, including 68 research platforms, 1,841 modules and 9,916 extension areas. Technologies improving sustainability of field practices were adopted on 159,944 ha that were monitored through a robust data collection system. Machinery to implement conservation agriculture and smart mechanisation was available for farmers in 18 machinery points across Mexico. Capacity development through a train-the-trainer approach resulted in 4,598 training events to farmers and 366 to farm advisors. In the 2018 summer growing cycle, 66,384 field logbooks were completed, resulting in a cumulative number of 221,961 records since 2012. In side-by-side comparisons of technologies, maize yields were 21% higher than control yields, and maize profitability was 41% higher. Wheat yields were similar in the side-by-side comparisons, and average wheat profits were 24% higher.

3.2. Application of AKM4I framework principles and processes in CIMMYT hubs

CIMMYT hubs prioritise the development of strong partnerships, where operations and activities are defined through reciprocal alliances formed around common objectives. Further, the elucidation of how stakeholders are expected to interact in partnership can be a first step towards more effectively navigating complex and often poorly defined power relations among different actors. In this sense, CIMMYT learnt to engage as a facilitator, connecting an intentionally broad and diverse network of actors, as well as providing technical and research services. Partnerships, co-creation, prototyping and experimentation continue shaping the work in the hubs and allow to work in collaboration with local communities fostering innovation, solving complex problems and increasing both productivity and sustainability (Liedtka et al., 2017). In 2018, 84 collaborations were formalised with local organisations; regional networks were analysed, proving that the hub model increases the probability of key actors becoming promoters – an ideal situation for innovation transfer-, decreasing communication costs, and indicating greater accessibility to knowledge (Roldán-Suárez et al., 2018).

In complex systems, the mediating role should not be filled necessarily by a formal research organisation; CIMMYT has found that its neutrality and apolitical nature has been important to fit the role and to interact with government actors of different political parties and convictions. Neutrality is also a condition to build trust in relationships, which is required for knowledge interactions (creation, socialisation, combination, externalisation, and internalisation). Trust tends to be built over time, so continuity is important, when short-term project funding is common in agriculture and development. It is worth noting that CIMMYT administers most financial resources for the innovation work in the hubs, especially research activities. While this role facilitates aligning collaborators around common objectives, it does skew the power in the relationship.

One of the strengths of the hub approach has been the constant science-based experimentation to learn and improve, working with farmers and key stakeholders to provide, through a user-centred methodology, integrated solutions to site-specific agricultural problems. The participatory research approach has allowed joint problem solving and learning, as the hub is designed and operates to test, validate and scale relevant practices (Liedtka et al., 2017).

The hub model structure, with platforms, modules, extension areas and the networks of stakeholders, allows the work to be context-specific at multiple scales. Research platforms focus on a specific production system, while modules and extension areas allow for more site-specific adaptation. Within one agro-ecological hub, there are geographic areas with distinct production systems, where relations are closer than with other geographic areas of the hub. Additionally, there are networks of collaborators that exchange knowledge across different hubs. This structure has fostered real interactions among farmers and the scientific community leading to a more equitable approach to knowledge generation, adaptation and adoption. For example, the research platforms are connected in a network at the country level, where local research collaborators use the same methods and exchange knowledge at national meetings, through communication channels like the bimonthly magazine and informal contacts.

Information flow is based on strong relationships among key actors, where relevant knowledge interactions occur either spontaneously or through a deliberate, organised process. For instance, socialisation and externalisation happen when traditional and expert tacit knowledge is shared verbally from farmers to extension agents and through a participatory process it is then tested in local research platforms. A concrete example is related to agro-ecological pest management, which is a practice that has been increasingly adapted and adopted by farmers (observational data from 2011 to 2018) since the hubs were established (Fonteyne, 2018). Another example occurs with internalisation of knowledge, where formal research results are translated into different formats to be shared with farmers and extension agents (technical training sessions, field days, SMS service, or Android APP). In 2018, the communication strategy also included a bimonthly magazine (18,000 printed units per issue), a weekly digital newsletter (6.500 subscribers), more than 150,000 information materials printed and distributed, and a systematic social network management (26,800 Facebook followers, 6,800 Twitter followers and 3.800 Youtube channel followers).

The CIMMYT hubs foster communication and partnership through the implementation of collaborative networks, and the design and deployment of relevant ICT tools. Specifically, extension agents apply field digital surveys to farmers who report crop cycle dates, management practices, inputs used, costs incurred, yields achieved, etc. They also load additional data (training reports, field visit reports, and socio-economic surveys) using ODK forms, an open data collection system. All submissions are subsequently saved and stored on CIMMYT's servers for further cleaning and interpretation. These tools, in conjunction with the infrastructural and relational networks built-in the innovation hubs, provide essential means of communication across the agri-food system and across a diverse array of stakeholders with different knowledge assets, priorities, and power dynamics.

The data analyses so far have been mostly descriptive analyses for yield, profit, agronomic practices, and training results. Diagnostics were used to conduct correlations, generate patterns and trends, mainly regarding yields, costs, soil health, greenhouse gas emissions and agronomic practices. Both the descriptive analyses and diagnostics have been used in project reports and communication to stakeholders in the weekly newsletter and bi-monthly magazine. Work on inferential, predictive and prescriptive analyses has started. In collaboration with the International Institute for Applied Systems Analysis (IIASA), a mobile app AgroTutor was developed that provides historic, non-nutrient and pest limited yield potential, based on a priori crop model outputs for 1980–2010, including geo-location of the field and associated data (soil, weather, etc.), cultivar characteristics, and whether the field is rain-fed or irrigated (Laso-Bayas et al., 2020 submitted). In another example, the agronomic data were analysed with machine learning algorithms to identify management practices related to higher yields and to build a set of site-specific recommendations (Laso et al. In prep.).

3.3. Future work

More research is needed to establish whether the hub model and the interventions to strengthen local networks and innovation have also been able to increase farmer empowerment in the long term, restructure power dynamics and inequalities at the local and national level or incentivise institutional and behavioural change. Application of systems theory and modelling techniques could help to understand higher system-level dynamics and identify correlated outcomes or patterns.

The hub model is flexible, and its application is inherently context-specific, but so far, CIMMYT has only applied the model in maize- and wheat-based systems in Latin-America. It would be interesting to apply the model to non-cereal crops with differently structured value chains, and in different cultural contexts to test what needs to be adjusted. For the application of the model in other contexts, capacity development with local teams is a condition for success. CIMMYT found that for hubs to be successful, the local team needs a combination of technical-agricultural knowledge, which gives them the credibility to be able to build relationships with value chain actors and identify sound recommendations, and skills related to knowledge management and brokering that are not commonly found in tradition research and extension roles.

4. Conclusions

The application of KM to agri-food systems has been challenged by a lack of clarity in the overall goals for "system" performance, structural disconnects in the transmission of information, and dynamics that intentionally or otherwise dis-incentivise positive changes at different scales. These implementation barriers have hindered the ability of KM to bolster innovation and development in agriculture. Through the outlined principles and processes, the AKM4I framework can assist in closing the cycle of continually re-creating knowledge, evaluating and iterating upon innovations, building coalitions to democratise knowledge access and utilisation, and using MEAL to facilitate course-correction of all stages of KM.

A complete establishment of this framework could allow to collect data from diverse sources (field, satellite, sensors), and use it to model complex agri-food systems, identify tipping points, elaborate relevant metrics and accompany intervention processes to guide positive innovation outcomes. The AKM4I provides a frame that considers some of the common pitfalls of KM for agri-food systems, to realise KM's potential contributions to innovation and improved systemic outcomes.

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