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Postharvest innovation in developing societies: the institutional dimensions of technological change

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Abstract
Purpose of review: This review aims to introduce the institutional and policy oriented literature on technological innovation into the context of postharvest engineering. The focus is how rigorous quality and food safety standards in cross-border agricultural and horticultural trade influence technological change up stream in the agri-food chain. The review presents a selection of literature that considers technological innovation as a process, with a specific focus on the enabling and constraining institutional conditions found in developing countries. The literature is grouped into three thematically defined frames: (i) interaction in systems of innovation; (ii) upgrading in value chains; and (iii) converging to pro-poor business models.
Findings: This review shows that the efficacy of innovation policies and strategies are not only related to technical choices supporting agricultural producers and small and medium sized food processing firms, but also to the institutional linkages and architectures in which innovation and technological change are embedded. Another important finding of the review is that although technology-oriented literature acknowledges the relevance of institutional and policy dimensions as well as the systemic nature of technological change, there is little connectivity between this literature and the scholarly work on technological innovation found in the social sciences and development studies.
Implications: The capacity to design and implement studies that combine an in-depth understanding of specific technological performance problems with novel institutional linkages is needed for enabling innovative capabilities in developing countries.
Directions for future research: Integrative research programs may be necessary to unravel the interdependencies between technological change and the social-economic and institutional environment in order to inform policy frameworks and business strategies to enhance innovation.

Keywords: innovation policy; quality standards; voluntary regulation; developing countries; institutional arrangements; agri-food chains

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Introduction
The quality and food safety requirements in cross-border supply chains for fresh produce and processed food products have become more strict and rigid. Private grades and standards, such as the Global Partnership for Good Agricultural Practice (GlobalGAP), which are installed to assure quality and food safety in a fiercely competitive market [1], are related to public regulation, such as the European General Food Law. Increasingly, quality requirements not only address basic food safety issues, which are related to the actual product, but also incorporate environmental sustainability and social welfare in the production process [2]. Moreover, grades and standards have shifted from a straightforward

technical instrument to a strategic instrument in differentiated and demanding product markets, leading to different strategic responses from firms, as well as to different alliances between private and public actors [3]. Grades and standards both set norms for behaviour and try to standardise or create uniformity [4]. These transformations in and new forms of regulation in primary production and processing impact the organisational structure and *modus operandi* of supply chains for agricultural and food products and pose major challenges for agricultural development [5, 6]. The new quality demands in consumer markets challenge productive organisations to adapt the ecological and social conditions of production [7] and to find new ways to coordinate innovation and technological change.

Implicit in the movement towards increased standardisation, ie, prescribing of Good Agricultural Practices, and regulation, ie, demanding compliance with safety and quality requirements, is that this trend is believed to automatically induce technological change and encourage innovative capability. The proposition is that integration into global value chains enables the development of technological capabilities in, for example, the South. Chain integration and market linkages provide the right conditions for developing countries to catch up with recent technological advances. This suggests that integration into value chains and linking small-scale farmers and processors to agribusiness or food companies will enhance the technological capacities of smallholder producers by way of cost-efficient technologies trickling down through the value chain or by quality requirements inducing best practices in performance [8].

This review is motivated by the observation that technological change may not follow automatically from chain integration and market linkages. Therefore, it seems worthwhile to approach technological change from the perspective of institutional interactions and arrangements, business and competitive models, and of hands-on problem-solving activities. A review of the literature with an interest in the institutional and socio-economic dynamics of innovation and technological change addresses the concern that the current concentration on mere compliance with technical standards and safety requirements in agri-food chains leaves aside the debate on how to effectively stimulate innovation and technology adoption among local enterprises and smallholder producers in the developing countries [9, 10].

The literature used for this review grounds technological innovation in agri-food chains in the complex institutional arrangements and feedback loops between technological praxis, diverse institutional architectures and social and economic environments. It emphasises the evolutionary and often contingent nature of technological change [11, 12]. This complements work on innovation management, which focuses more on the organisational and managerial dynamics of R&D inside firms from the perspective of competitive advantage [13–16]. In this paper, technological innovation is defined as the implementation and commercialisation of anything new with improved performance characteristics or improved services into an economic or social process [17, 18]. Technologies in agri-food chains appear in the form of artifacts (eg, seeds, chemicals, or postharvesting machinery), guidelines and rules in contracts or standards, and in the language and actions of technicians and auditors.

Technological challenges in postharvest innovation

An important focus of the technology-oriented postharvest literature is on adding value, reshaping quality control systems and product standardisation, enhancing market access through transport, storage and processing facilities, and reducing losses through improved postharvest systems and the integration of postharvest engineering and physiology [19]. An important proposed response to, for example, quality deterioration, is to make adequate technologies available. The requirement for traceability is often approached by working on technical means and systems within the context of complex divisions of labour or of conflicting interests within a value chain [20].

Interestingly, the importance of the institutional dimensions of technological innovation, such as adaptation to local circumstances, policy frameworks, creativity, appropriate management systems and capacity building, is also acknowledged in this technology-oriented literature [19, 21]. Notions like participatory design and intermediate, tailor-made technologies have received increased attention since practice has shown that generic technological solutions do not necessarily work under different socio-economic and agro-ecological conditions [22]. From a development perspective, postharvest is related to the development of labour-intensive rural agro-enterprises that are able to create added value in (marginalised) rural areas [23]. However, the emergence of global value chains is equally considered a potential reason for the exclusion of small-scale farms and enterprises [21].

In the literature on postharvest problems and solutions, there seems to be a professional bias towards technical responses and the dissemination of expert knowledge while the overall complexity of the transfer and adaptation of technologies is ignored [24]. The three thematic frames described below: (i) interacting in systems of innovation; (ii) upgrading in value chains; and (iii) converging to pro-poor business models, may open new avenues for combining the development of technological solutions with processes of institutional change. Most of the emphasis in this review is on approaching the process of technological innovation from a systems perspective. The other two themes can best be seen as complements to or comments on this approach.

Interacting in systems of innovation

The introduction of relatively uniform technological practices and standards puts much emphasis on the development of productive capacities for transferring technological packages that originate in industrialised businesses or R&D organisa-

tions to the growers' fields. This has the risk of overruling the diversity of agricultural production, processes and trade, embedded in local social and economic systems. It makes innovative capacity in agri-food chains strongly dependent on exogenously determined knowledge and skills, held by the lead players. Consequently, the pattern of development in agri-food chains reinforces a unidirectional technology transfer model that has been seriously questioned [25].

In the history of agricultural development, public research institutes have featured prominently as lead agencies in introducing technological change. In particular, their role in introducing new crop varieties in the Green Revolution has been an important element of development practice and debate. To a lesser extent, postharvest technologies have been developed by public research institutes working in collaboration with technology firms. A technology-push approach to innovation and technical change often dominated the working environment in these systems.

The systems of innovations framework responds to this technology-driven approach by emphasising the importance of continuous interactions between users and providers of knowledge and technology. It considers the individual capacities of public and private actors as elements of a larger system of innovation [26–29]. A system perspective implies changing the institutional architecture of technology development and diffusion. The current set up resembles a globally coordinated agricultural research system, diffusing appropriate technologies linearly through a multilayered institutional architecture through national research institutes to local users. The system perspective considers such an architecture at odds with the realities of research and technological change at a local and national levels and with the bio-physical and socio-economic heterogeneity that characterises, for example, rural Africa [30]. A system perspective on innovation aims to open possibilities for social inclusion and building on ongoing pro-poor innovation processes in specific localities [31]. For this purpose, new types of institutional arrangements and processes need to be installed.

The National System of Innovation framework takes an interest in existing market structures and social institutions bringing about endogenously determined technological opportunities. The patterns of behaviour and partnerships, and the rules and regulations governing them, are usually located in the setting of a national system of innovation [32, 33]. An innovation system can be seen as a web of actors active in a specific technological system, which is accompanied by a certain infrastructure and various forms of knowledge exchange [34–36]. In this sense, an innovation system connects distributed technical knowledge, which broadens the scope from individual technologies and organisations to systems and networks [37]. This makes management of the interaction between competencies and forms of innovation in various sub-units an important task in the innovation system [38–41].

The perspective also implies an integrative analysis of different types of social networks and processes for innovation and learning [42]; the formation of and interactions within such networks, constraining or enabling influence, may also help to explain why the diffusion of (irreversible) innovations fails or succeeds [43]. For example, the diffusion of a high-resolution remote sensing technology developed in a rather isolated and publicly supported R&D organisation in India was constrained by the social and political realities of land distribution and ownership in rural areas, creating inconsistencies and tensions within a national system of innovation [44].

In the debate on technological change in developing societies, Hall and colleagues used the National System of Innovation framework in an argument to shift the focus of development policies from fixed technological packages to the processes of research and development [26, 45, 46]. Interestingly, this line of work started with a case of postharvest innovation: the packaging of tomatoes for urban markets in the Himalayas [47, 48]. This work started with the problem that a technology can be introduced successfully by an external agent, but what happens once the external agency withdraws? The authors point to the importance of installing mechanisms that enable viable long-term resilience and problem-solving in a robust system that includes a collection of capabilities that does not rely on a single technology. This approach locates technological change in an evolutionary process of learning and continuous change, which implies a focus on the multiple interactions between various public and private organisations, wherein technologies are selected and tested.

The innovation system framework used by Hall and colleagues considers innovation as a dynamic and interactive process rather than a linear process. It takes an interest in institutional mechanisms and arrangements patterning behaviour and interactions [26]. Basically, the framework entails a critique on technological expertise and knowledge "locked up" in research institutes. It states that R&D organisations need interactions with users (eg, farmers) and commercial settings (eg, value chains), which are hampered by a rigid institutional distinction between research and diffusion. The innovation system framework proposes a policy shift in constructing a viable and flexible institutional environment, in which technological opportunities evolve, rather than supporting a predefined search for suitable technological recipes by R&D organisations largely disconnected from their environment and actual users. In this perspective, local institutions and innovation networks act as translators of external technologies, in order to provide technical solutions tailored to specific circumstances. Simultaneously, these actors are seen as providers of feedback to national and international R&D systems, with the idea to set research agendas flexible enough to incorporate local needs and demands [49, 50].

Intarakumnerd relates the System of Innovation framework to the development of (agro) industrial clusters in Thailand, which link both primary production, processing and value-

adding functions [51, 52]. These studies observe that the innovation system in Thailand is weak and fragmented, resulting in slow technological learning. The absence of an organisation managing the interactions between actors with different technological capacities can lead to fragmented and non-responsive technological infrastructures in developing countries. Low connectivity between users of technologies, R&D organisations and universities may help to explain the difficulties developing countries face in catching up [53–55].

The above authors define the challenge for the Innovation System approach to have an impact in the transitional economies. Experience in Thailand suggests that intermediaries are the most effective target groups for innovation policy. Moreover, the approach embeds innovation in the vertical linkages between suppliers and buyers in chains and emphasises the need to involve non-agricultural actors in innovation policy [56]. In the case of grilled fish chilli paste, this was a firm introducing canning technologies to increase the shelf-life. The experience in Thailand complements the system of innovation view with the realities of local and regional social structures, including many small scale firms, and the close alignments between suppliers and buyers connected in a value chain. Furthermore, it adds interest in the institutional capacities for managing the interdependencies and patterns of specialisation underlying the evolving innovative performance in a cluster or value chain [57]. Research in Tanzania underlines the importance of non-market mechanisms shaping connectivity and collaboration among local firms in technological learning. This perspective, grounding technological innovation in a local industrial base for incremental upgrading, provides an alternative to policies concentrating on importing new technologies or enabling positive spillovers from foreign to domestic firms [58].

Critical readings of the national systems of innovation literature note a bias towards the structure and reform of the brick-and-mortar public sector organisations, rather than on the "rules of the game" underlying priority selection and agenda setting in technological innovation [59, 60]. It seems relevant to understand more about how organisational cultures, behaviours and social practices change and are changed in order to reform the functioning of innovation systems [18]. The process orientation and the bias towards the public sector tends to set aside negotiations and conflicting interests in the economic realm, which importantly determine how innovative capabilities are shaped and what technologies are selected [61]. The two frameworks discussed below have an explicit outlook on technological upgrading in value chains and on the relevance of reconsidering current business models.

Upgrading in value chains

Experience with weak and fragmented systems of innovation in developing countries indicates that institutional change in the commercial domain may improve the pace of technological learning in a sector or chain. Public research organisations tend to concentrate on generic R&D and put less effort in building lower level capability such as technology assimilation and adaptation, design and engineering [53]. The combined approach to regional innovation systems and specialised economic clusters in Thailand puts forward the challenge of leveraging micro innovative strengths through systemic change at the meso level [51, 52]. A possible consequence of this weak link between micro and meso levels may be that actual upgrading, such as building capacity in design, R&D and engineering is difficult to achieve.

The work of Humphrey, Schmitz and colleagues [62–65] on upgrading in value chains raises an important question: how do changing value chain relationships affect these processes of learning and innovation as well as the acquisition of technological capabilities? This literature emphasises inter-firm cooperation and local institutions in the process of upgrading, and makes the process of upgrading dependent on the ways firms or clusters are inserted into (global) value chains. These processes of integration often come along with hierarchical divisions of labour, allocation of tasks by lead firms and asymmetric relationships. In value chains, the process of integration and the making of institutional arrangements are largely coordinated by a lead firm [66, 67]. Consequently, lead firms, for example supermarkets buying fresh produce, may be driving technological change by prescribing the implementation of specific modes of processing and packaging or of certain logistical systems [63]. This also suggests that national or regional innovation systems and industrial clusters cannot ignore the institutional and governance consequences of external linkages induced by the globalisation of trade and economic integration with distant markets [68, 69].

Specialisation in the context of cross-border value chains may make agro-industrial clusters and agricultural producers more vulnerable because they lack effective linkages with other actors to enhance their technological and innovative capabilities. However, through acquisition of technological capacities or specialisation in certain tasks, value chain actors may also strengthen their capacity to respond to new regulatory requirements and market opportunities. This introduces the interesting field of mixing endogenous and exogenous knowledge and skills, which entails complex institutional arrangements between local actors and outside organisations. Although sourcing strategies and decentralised business practices closely interact with diverse conditions and a variety of producers and processors, appreciating the benefits of the existing social infrastructure is not strongly rooted in the value chain strategies of firms participating in globally dispersed production systems [70]. In cross-border value chains, this leads to narrowly defined roles for developing country producers, with correspondingly limited technological capacities [62].

The analysis of global value chains in a variety of sectors leads Humphrey and Schmitz [71] to hypothesise that in value chains characterised by (quasi) hierarchical management styles and one-sided regulation through grades and

standards, developing country producers experience rapid upgrading through the implementation of proven technologies in the production process and a move into more sophisticated production lines or markets. However, their function may be limited to more peripheral activities in the value chain. The proposition is that local producers in developing countries, embedded in networks and open-ended systems of innovation, rarely find themselves in more integrated value chains. This, however, is not necessarily a fixed outcome, and future perspectives depend on the changing nature of the relationships and modes of governance.

Converging to pro-poor business models

A consequence of the previous discussion is that business models and management strategies do matter when aiming for enhanced innovative capabilities and performance capacities among upstream producers and processors in an agri-food chain. One of the implications of the literature discussed above is to examine the enabling or constraining conditions for agricultural producers to become decision makers in competitive markets for new production processes and services rather than to be receivers of technologies developed in public or private R&D departments.

Prahalad and his colleagues have pioneered new approaches, labelled as "bottom of the pyramid", linking the private sector to poverty alleviation strategies [72–74]. Their core argument is to stop thinking of the poor as victims and start recognising them as resilient and creative entrepreneurs and value-conscious users of innovative technologies or novel services, thus constituting a market. The idea is that, from both a commercial and a developmental perspective, many firms mistakenly ignore these markets of lower income groups in developing countries.

The literature has a specific interest in innovations that take root in less demanding applications among non-traditional customers that are capable of achieving significant price reductions without compromising quality [75]. The approach does not require major technological advances, for example through major investments in generic technologies such as genetics or nanotechnology, but relies on tailoring quality products and processes to the demand of customers with lower levels of incomes. This requires firms to be able to manage a variety of business models and market strategies, which ensures the needed flexibility in approaching non-traditional markets [74]. It also involves development of new products or services capable of adapting to fixed or less malleable constraints. This contrasts with a business model that only succeeds under "ideal" conditions, more often found in top-segment markets, where development costs are recouped by high introductory prices.

The focus of this review is on innovative capabilities in relation to productive and industrial processes in agri-food chains [25, 76]. The next two examples reveal how, in India, technological change in sugar and soy chains was accompanied by new business models. In the sugar chain, a corporation running a sugar factory decided to set up internet kiosks [77]. The corporation already maintained close linkages with the farming communities, as a buyer of the produce and as a provider of farm inputs. The internet kiosks used a franchise-based business model. Access to the internet was leveraging information and communications technology (ICT) in three areas in the agri-food chain: distribution of inputs, trade in farm products, and communication and information. The case study describes how the internet kiosks enabled the dissemination of knowledge on agricultural technologies, supported the demand for knowledge, provided information on the markets for selling goods and generated information supporting transparency in prices. A similar case study in an Indian soy chain shows how a trading house used information technology to reengineer procurement practices through a village-based information centre linked to the internet [78]. The viability of this procurement practice was related to the opportunities the information centre offered to obtain knowledge about weather conditions for articulating crop specific interventions and for communicating information making the price-quality relationship transparent. The trading house used the philosophy of modular increments acknowledging the specific conditions in the villages and the trading system.

The framework discussed here has a strong bias on individual entrepreneurs, favouring technology-based entrepreneurship and building on available tacit knowledge and skills. The approach is less explicit about the nature of the relationships between economic actors compared to the literature on upgrading in global value chains or on the interactions in systems of innovation. Due to the strong focus on bringing new products and services to local markets, the approach pays less attention to the processes through which local entrepreneurs gain entry into design, production or marketing networks elsewhere. The approach prefers business models leveraging the strengths of markets and social infrastructures rather than those focusing on overcoming or correcting weaknesses, as grades and standards tend to do [70].

Conclusion

The literature discussed in this review contrasts with a seemingly established practice in many (public) research organisations that organises innovation as a sequential activity and sees technological change as an outcome at the end of a pipeline through which knowledge and tools flow down to the actual user. Grades and standards prescribing certain performance levels in agriculture seem to adopt a similar linear notion of technological change. The review asked whether such an institutional perspective on technological change is commensurate with the technological sophistication of meeting high level performance requirements and with the complexity of engineering postharvest practices under real agro-ecological and socio-economic conditions.

The three frames examined in this review share an interest in the efficacy of introducing or transferring exogenous tech-

nologies into agricultural and postharvest practices, and include perspectives for understanding the institutional dimension of socially embedded technological change. They discuss: (i) how technological change originates in the institutional dynamics among actors linked in a system of innovation; (ii) the possible tensions created by the hierarchical dimension of value chains for technological upgrading in local innovation networks; and (iii) the probable efficacy of new business models embedded in a reconfigured value chain structure.

The literature suggests that effective technological innovation in agri-food chains implies a synthesis through iteration and negotiation between various actors assembled in a layered organisational framework [79, 80]. Some form of coordinated innovation, in which both market opportunities and institutional arrangements are integrated, may be needed to enhance the innovative capacities of chain actors and adjacent organisations for leveraging sustainable development [81, 82]. Building such a collaborative model, instead of relying solely on economic efficiencies and standardised practices, requires purposive and strategic interventions and investments by chain actors in alliances with other actors.

Agri-food chains that have to cope with stringent performance requirements in competitive markets can be considered as important socio-technical arenas to explore new ways of managing innovation and technological change. The institutional challenge is to understand how actors operating at different scales or nodes in agri-food chains and systems of innovation combine their tasks and performance skills in problem-solving and incremental performance improvement [80, 83–90]. Perhaps, ensuring fitness and efficacy of technological change implies that postharvest engineers concentrate strongly on making it happen (for an example see the work of the Post-Harvest Innovation Learning Alliance, PHILA), rather than on drawing designs and developing technical products [91]. Here also lies an opportunity for interdisciplinary work between natural and social scientists who try to unravel the interdependencies between the biological [92, 93] and the social or institutional dimensions of performance and technological change. From the development perspective central to this review, it seems appropriate to focus on the abilities to perform and innovate under conditions of “scarcity” [94] found in the transitional economies.

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