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R&D AND THE TRANSFORMATION OF THE FOOD SYSTEM: A CONTRIBUTION OF THE INTER-AMERICAN INSTITUTE FOR COOPERATION ON AGRICULTURE (IICA) TO THE UNITED NATIONS FOOD SYSTEMS SUMMIT 2021

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Editorial coordination: Federico Villarreal
Mechanical editing: Olga Patricia Arce
Translation: Catalina Saraceno
Layout: Nadia Cassullo
Cover design: Nadia Cassullo
Printing: IICA Print Shop

Gianoni, Cecilia
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1

Introduction

This note seeks to promote discussions about the contribution of R&D to the transformation of food systems within the framework of the upcoming United Nations Food Systems Summit. There are three main triggers for this change: a) the world's population will continue to grow before stabilizing in 20-30 years; b) there is evidence of changes in consumer patterns; and c) significant impacts are expected due to climate change.

We are aware that innovation is a key element for achieving this transformation and that it continues to pose a challenge for the countries of Latin America and the Caribbean (LAC). However, this note will focus on analyzing the opportunities and the challenges for agricultural R&D as a sub-system integrating the innovation system with a strategic role.

The proposed objectives for the Summit point to the need for significant changes with respect to production systems that lead to balancing the necessary increases in productivity with sustainability in the medium to long term; closing the existing gaps within and between countries; reducing the vulnerabilities that persist in the territories; adapting and mitigating the impacts of climate change; and ensuring global access to food that is of good quality, is nutritious, has a low environmental impact and is socially responsible.

R&D is an essential component for achieving all these objectives. In this regard, the current scientific-technological scenario represents a great opportunity that we must seize, as it is characterized by its accelerated and intense modifications to the form, type, impact and speed with which science and technology (S&T) occurs; by the advances in new models of organization and governance; by strengthening of the interdisciplinary and transdisciplinary approaches; by the emergence or consolidation of new actors in the global food markets; and by changes in the measures for protecting intellectual property rights.

The pandemic has only highlighted these challenges and opportunities. On the one hand, it has shown the importance of having solid agricultural systems. The agriculture sector in LAC maintained its activity during the health crisis –see the hashtag #AgricultureisOpenforBusiness (#ElCampoNoPara in Spanish)– and supplied various corners of the globe with quality food in sufficient quantity. This ensured that the workforce along the entire food chain was kept occupied and generated income and foreign exchange. This reality required the development of strategies for the generation and application of sanitary protocols in the various productive processes and in the interaction of the agriculture sector with the health sector, and of the transport industry with that of telecommunications, among others. On the other hand, the pandemic accentuated the requirements for new knowledge and technologies that ensure flexibility in the processes, more efficient use of natural resources, minimization of waste and losses, care of the environment, and improvement of the social and equity aspects.

This note is structured along two lines. The first is linked to R&D in agrifood as an instrument for transformation of the food system, in which the capacities available in the countries of LAC are taken into account. The second axis analyses the opportunities and the challenges of R&D in agriculture within the region in its contribution to the five modes of action (MA) defined by the Summit, and integrates inputs emerging from the Independent Dialogue carried out jointly by the Inter-American Institute for Cooperation on Agriculture (IICA) and the Cooperative Program for the Development of Agricultural Technology in the Southern Cone (PROCISUR) on July 22nd, 2021. Finally, some thoughts on the topic are presented.

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Agricultural R&D as an instrument for transformation of the agricultural system

Empirical evidence shows that investment in agricultural R&D in the LAC countries has contributed to agricultural development, to economic growth and to poverty reduction in the region. New technologies resulting from investment in R&D have improved the quantity and quality of agricultural production, while increasing sustainability, reducing food prices for the consumer, enabling rural producers to have better access to markets, and increasing male-female involvement as well as the accumulation of physical and human capital within the homes (Stads *et al.* 2009:2).

Based on the assumption that national agricultural research systems that are well designed and have adequate levels of investment are essential to agricultural development, food reduction and poverty reduction, many LAC countries have been making efforts since the beginning of the century to adapt their research, development and innovation systems (R&D&I) to the new scenarios. In this regard, several national agricultural research institutes (NARIs) have built their research capacities both in terms of the number of researchers as well as the level of academic training, with renewed models for management and governance, moving towards participatory research processes, networking and public-private platforms. However, there are still outstanding matters relating to R&D capabilities and institutional frameworks, in particular as it relates to the public sector in light of the Covid-19 pandemic.

The main hurdle to overcome relates to the levels of investment in agricultural R&D in LAC as these are significantly below the required level. Although, throughout this decade, the region has, percentage-wise, been increasing its investments, the region has only invested, as a percentage of its agricultural gross domestic product (GDP), less than half of the average amounts invested by developed countries (only 1.5%, compared to 2.5%) and with very unequal trends between the countries (ASTI/CGIAR)[1]. 2013 figures show that while the majority of the countries in the Southern Cone – Brazil (1.82%), Chile, Uruguay and Argentina were above 1.20%, and the English-speaking Caribbean, Costa Rica and Mexico were at 1%, the rest fell below this figure, sometimes considered as the minimum

(1) Calculation of the level of investment in R&D does not include the profit-making private sector ASTI/CGIAR. Benchmarking Latin America and the Caribbean. Expenditure / Percentage of agricultural GDP. https://www.asti.cgiar.org/es/benchmarking/lac (consulted on 18 January 2021).

for maintaining an effective R&D system. Eight countries[2] had made investments of less than 0.4%, with Guatemala being the country in the hemisphere that had made the lowest investment of all (0.14%). Although these are 2013 figures, the current picture has not improved, and these amounts will fall significantly in the upcoming years as a result of the pandemic. In 2020, budgetary restrictions in the order of 50% were reported by the majority of NARIs in LAC, with negative consequences on R&D processes (personal communication)[3].

This results in different capacities to generate R&D strategies which, when added to the existing diversity between the countries (geographical, economic, social, cultural and climate-related) has resulted in large gaps in productivity, particularly in the smaller countries and in the tropical areas (Nin-Pratt *et al.* 2015). One exception in this regard is Brazil which, over the past 40 years, has developed an endogenous tropical agriculture model for selection and adaptation of crops that are of interest for agriculture, with a continuous increase in productivity, employment and income generation, value added, increase in the quality of life in rural areas and positive impacts on the care of the environment (Albuquerque *et al.* 2008). However, these advances have not spread to other tropical countries in the Americas where much remains to be done with respect to natural resources and biodiversity.

In turn, the States continue to be the main engine for investments, which is contrary to the global trend of more dynamic participation from the private sector (Fuglie 2016)[4]. In low and medium income countries, this trend is more visible. According to Pray et al. (2015, cited in Fuglie 2016) the technology policies (particularly in biotechnology and intellectual property rights) that facilitate participation by multinational corporations can significantly encourage investment in agricultural R&D from the private sector as well as foreign companies.

Although most of the agricultural R&D is carried out by companies located in developed countries, over the past couple of years there has been growth in R&D investment by companies belonging to emerging economies. Brazil is one of the countries in the region that have developed policies to incentivize private investment. This includes unlocking multinational participation in its local agricultural inputs markets, as well as intellectual property rights for new varieties and regulatory protocols for approval of genetic events.

Flugie (2016) stresses the importance of adjusting the government R&D portfolio by including elements from the private portfolio. He also mentions aspects such as the opportunity and the challenge of working on public-private investments and

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(2) Nicaragua, Peru, Venezuela, Dominican Republic, Paraguay, Ecuador, Honduras and Guatemala. ASTI/CGIAR. Benchmarking Latin America and the Caribbean. Expenditure / Percentage of agricultural GDP. https://www.asti.cgiar.org/es/benchmarking/lac (consulted on 18 January 2021).

(3) Members of the Board of Directors of PROCISUR. 31 July 2020. LXVI Meeting of the Board of Directors, virtual conversation. INTA Argentina, Embrapa Brazil, INIA Chile, IPTA Paraguay and INIA Uruguay.

(4) Private global investment in R&D tripled between 1990 and 2014. Although most of the countries that are making these investments are located in developing countries, and are commodity providers, their technologies are becoming more important for the developed countries (Fuglie 2016).

the need for public R&D to address the demands of the farmers in areas where the incentives for private R&D are low. Additionally, empirical evidence gathered by Anríquez *et al.* (2016) shows that the orientation of public spending towards obtaining public goods, as in the case of R&D investments, has had a positive influence on agriculture in LAC[5].

The situation with respect to family farming (FF) also constitutes a challenge, based on the economic and social weight it carries. It represents a high proportion of farms in the region, and it is estimated that it accounts for almost 60 million persons. It is the main source of agricultural and rural employment and contributes significantly to local and national food security (FAO *et al.* 2019). According to the Food and Agriculture Organization of the United Nations (FAO), mitigating the impacts of the pandemic in the food system requires, among other actions, that specific contextual solutions be chosen which use the resources and goods that are available locally, which puts FF in a very good position to provide solutions that are rooted in the territories and communities[6]. This sector is key to achieving the Sustainable Development Goals (SDGs) because of its multidimensional nature, and can contribute to food and nutrition security, to the management of natural resources, the preservation of biodiversity and cultural heritage and to climate change mitigation.

Finally, the design of R&D systems should go hand in hand with extension and participatory models that involve farmers and other actors in the food system, which are key to introducing innovations that have a positive and equitable impact on all of them. If we observe the global innovation indices for 2020[7] (Cornell University *et al.* 2020), we find that LAC is in the penultimate position worldwide (27.76), only above Sub-Saharan Africa, and has numbers that are vastly below the 56.45 index for North America or 35.02 for Asia.

Scientific and technological advances that are not accompanied by public policies, appropriate regulatory frameworks, good coordination of existing technical and technological capabilities, development funds, private investment and active participation by productive stakeholders may not be transformed into innovations and may not yield the expected benefits. The use of the powerful instruments for change currently being developed by science and technology (S&T) depends on our capacity as countries and region to generate and strengthen organizational, financial and human resources. In addition, an institutional environment must be created to promote change in the way food is produced, from the logic of "consuming what is produced to producing what is consumed", while recognizing and managing the growing socio-productive heterogeneity and institutional diversity existing in the region.

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(5) The authors draw attention to under-investment in public goods (infrastructure, technology and knowledge) in the countries where there is a majority of small farmers with limited capital, a situation that leads to a weakening of growth in the sector (Anríquez *et al.* 2016).

(6) FAO. Family farming knowledge platform. Covid-19. http://www.fao.org/family-farming/themes/covid/en/ on 5 February 2021.

(7) WIPO (World Intellectual Property Organization). Global Innovation Index 2020. https://www.wipo.int/global_innovation_index/en/2020/ Consulted on 29 January 2021.

New technologies open up excellent opportunities. The current development of software applications (apps) for agriculture and the massive use of social media have increased the circulation of science-based information that previously did not reach the public. This implies a great change and a challenge for S&T organizations, which must adapt and pivot towards local needs and production systems and must be based on science and evidence to respond to the challenges that some of them may have to face in society.

Attention to all these aspects in a very adverse financial context such as the current one strongly reaffirms the institutional challenges already identified by Sain et al. 2009, referring to the need to: a) increase and diversify investments in R&D, both public and private, whether direct or through partnerships, without which it will be very difficult to achieve the SDGs; b) develop capacities that incorporate new knowledge and disciplines for the application of cutting-edge technologies by valuing environmental, social and cultural aspects; and c) strengthen the institutional organization of the R&D system in the countries, including the public sector in its role as promoter and generator of public goods, but also networks at the country, regional and international levels that promote technical and financial cooperation.

With respect to the first of the challenges, Mateo (2019) adds another avenue for financing or co-financing R&D, linked to the national or regional philanthropic sector, which is in a stage of strong growth. However, he draws attention to the fact that in LAC the sector is less structured and less well known[8] and that contributions from the United States and Europe are declining in LAC in favor of regions such as Africa and South Asia, which are characterized by extreme poverty. In order for LAC agrifood R&D to capitalize on the opportunity provided by this sector, countries should establish modern legal frameworks and clear administrative, operational and control rules, in addition to creating linkages between donors and interested sectors and regions (Mateo 2019).

(8) A excepción de Brasil y México, que concentran alrededor del 50% de las personas millonarias de ALC.

3

Opportunities and challenges for R&D in the region in its contribution to the five ATs

The development and use of new technologies such as digital technology, robotics, artificial intelligence, the Internet of Things, biotechnology and nanotechnology are transforming agriculture and food production and governance systems in the world. They have modified or replaced certain production factors and have had profound broad-spectrum impacts on the economy, social organization and the environment (Trigo *et al.* 2019). Furthermore, the synergy of agronomic and ecological knowledge has grown towards holistic approaches for the management of natural resources in agroecosystems (Andrade 2017). These disruptive technologies accelerate processes, making them more precise and capable of processing a large amount of information while reducing costs, thereby facilitating the development of more affordable technological innovations at a faster pace.

Here we raise a number of challenges and opportunities that require contributions from solid scientific bases, productive alternatives and creativity by the region's agrifood R&D systems. While many of the issues are on LAC countries' agendas, these are still open debates. Based on the goals of the five ATs[9], we group the discussion into three complementary areas, 1) productivity and sustainability of food production systems; 2) access and affordability; and 3) nutritional quality and health.

3.1 Productivity and sustainability of foods

Greater global demand for sufficient, high-quality nutritious, healthy foods, with low environmental impact and from socially responsible production systems, resulting from driving forces such as population growth and migration, combined with urbanization processes and changes in consumption habits caused by increased income in certain sectors and regions (Von Braun *et al.* 2020) cannot be covered solely by the expansion of the agricultural frontier. The answer lies in increasing productive efficiency by surface unit, based on new knowledge that requires R&D.

(9) AT1: Ensure access to safe and nutritious food for all; AT2: Shift to sustainable consumption patterns; AT3: Boost nature-positive production; AT4: Advance equitable livelihoods; AT5: Build resilience to vulnerabilities, shocks, and stress (von Braun *et al.* 2020).

The challenge of sustainable intensification

Sustainable intensification processes that started twenty years ago in many of the countries of LAC require greater knowledge and alternatives of new production models that add environmental value to the region's products and tend towards a gradual improvement in ecological efficiency. It is hoped that technologies will help reduce dependence on external inputs and non-renewable resources, maintain and improve natural resources, increase productivity and profitability with lower environmental impact, and promote equity and social inclusion (PROCISUR 2016).

It is important to integrate visions and concepts that are not understood unequivocally today, but which pursue the same goal of making the necessary processes of intensification more sustainable, so that they include fully agroecological systems and traditional systems in which green technologies are incorporated. The intensification processes must be adapted to the agroecological conditions, to different production systems and to the size of producers in each area or region.

One priority for the R&D agenda is to generate and validate indicators that monitor and evaluate the sustainability of these processes locally and regionally. To do so, it is necessary to have multidisciplinary research teams and the participation of stakeholders within and outside the S&T system, in order to consider all the dimensions of sustainability and its attributes, such as the socioecological characteristics of the processes to be evaluated (Aristide *et al*. 2020). The attainment, measurement and evaluation of local sustainability and scientific indicators will position the countries in global indicators generated internationally, with real information on the impact of food production on the health of the planet in the six dimensions: greenhouse gases (GHGs), soil use, water use, nitrogen (N) use, phosphorus (P) use and biodiversity (Herrero *et al.* 2020). In this regard, digital technologies, through remote sensors, drones and satellite images, constitute an opportunity to promote the rapid attainment in real time of many of the indicators that are prioritized. This will reduce decision-making times in the management of productive systems and appropriate content will be provided to public policy and regulatory instruments, among other benefits.

It has also become necessary to democratize information and knowledge and to seek alternatives to bridge gaps in the rural populations' access to and use of these technologies.

The sustainability of livestock systems

Regardless of the strong trends that can currently be observed (Glopan 2020), animal protein is a basic component of the human diet, providing vitamins, minerals and amino acids essential for the human body (IICA 2020a and 2020b). Furthermore, livestock farming is a central activity of many economies in the region, including those where FF predominates. Likewise, it is a key component in the upkeep of pastures and provides important ecosystem services[10] (Oyhantçabal *et al*. 2010).

This means that the sustainability of livestock systems is a constant challenge in the countries of LAC, and it is therefore urgent to continue generating scientific evidence, technologies and management practices that lower GHG emissions,[11]reduce the use of freshwater and agricultural lands, and ensure animal welfare. Many countries and subregions with collaborative R&D projects are conducting research into areas such as diet, management and animal genetics, and ecosystem services.

In this regard, it is important to highlight the gathering of evidence on the impact of the quantity and quality of diet in reducing methane emissions,[12] and the advances in the following fields: a) animal nutrition, as a result of developments in precision feeding, exploring the animal microbiome and evaluating and incorporating new inputs for animal feed; b) the genetic breeding of animals by genomic selection of feed efficiency characteristics;[13] c) the use of advanced reproduction techniques and precision improvement methods; and d) animal welfare, which is an increasingly relevant demand from international markets. Research into good management, nutrition and health practices must continue and go further (IICA 2020a), including research into the use of new biotechnological techniques.[14]

Furthermore, the impacts of integrated systems[15] on carbon neutral livestock production have been showing successful results. One example of this is the creation of the framework-concept "carbon neutral beef" (Alves *at al.* 2015) created by the Brazilian Agricultural Research Company (EMBRAPA), which in 2020, along with the company Marfrig, launched a new sustainable line of beef (Viva line) into the Brazilian market. Integrated systems not only contribute to environmental sustainability, but also generate income for small producers, which makes them less likely to leave the rural milieu and reduces countryside/city internal migratory processes.

It is necessary to generate and make available local data on the balance between carbon emissions and sequestration and the impact on livestock systems in LAC, accompanied by the action plans of national inventories and commitments from every country made in international agreements.

(10) Such as maintenance or increase in carbon reservoirs, prevention of erosion, production of green fertilizers, improvement in water quality and maintenance of animal and plant diversity (Oyhantçabal 2010).

(11) Livestock is responsible for 57% of emissions generated by the agricultural sector in LAC (FAO 2020a).

(12) Some evidence collected in livestock systems in Uruguay shows that high-quality diets (low percentage of fibers and high digestibility) with access to fresh and clean water can reduce methane emissions by up to 14% per kg of dry material that each animal ingests (Dini *et al.* 2017).

(13) Decreases have been recorded of up to 25% less methane than in low-efficiency animals (Dini *et al.* 2017).

(14) More recently, work is being done on the application of gene editing to contribute to improving animals' living conditions. One example, cited by Feingold *et al.* (2017), is the production of cattle without horns.

(15) Current integrated systems focused on cattle in LAC countries are agricultural-livestock, livestock-forestry and agricultural-livestock-forestry (Almeida 2017).

The opportunity of bioeconomy and the circular economy

The new paradigm of the bioeconomy requires R&D capacities to develop technologies and new alternatives that progressively substitute fossil fuel products with renewable resources of biological origin and minimize losses throughout the value chain, in order to make the use of biomass more efficient in the production of food and energy (Rodríguez *et al.* 2019). LAC has great potential to base its development strategies on the bioeconomy, together with the circular economy, given that it is one of the most important photosynthetic platforms in the world and has a wide range of potential biological inputs that are not currently harnessed[16].

The increase in productivity that generates less waste is a conditioning factor for the sustainability of systems, although it also creates other costs. Therefore, it is necessary to have more knowledge on the cost-benefit relationship in the production of bioinputs and renewable energy sources.

The development of integration mechanisms closer to production and commercialization systems in short agrifood circuits would lead to a reduction in waste, mainly of fresh foods, which involves changes in consumption patterns.

The recirculation of byproducts and the reuse of waste in the value chain in food and other sectors requires greater R&D evidence of its impact on the provision of ecosystem services in agrifood production, the mitigation of climate change, the recovery of soil and decreased water, soil and air contamination, among others (Rodríguez *et al.* 2019).

The substitution of fossil fuels continues to be debated, with poor assessments of impacts and the environmental and social tradeoff of the use of agricultural soil for food production and for energy production. The discussions re-emerge depending on international oil prices, hence scientific knowledge is required of the long-term impact of biofuel production. It is necessary to continue to strengthen the development of alternatives that do not compete with food production, such as lignocellulosic biomass for the production of bioethanol, on which research has already been underway for several years. It is also important to develop and validate assessment methodologies of the environmental, social and economic impact and of the energy balance (Salles *et al.* 2009).

Adaptation to climate change

As a consequence of climate change, the number and intensity of natural disasters in LAC countries has intensified in recent years, especially in the form of weather events such as droughts and floods. Given the interdependence between climate

(16) LAC has a high percentage of waste in the value chain (36%). Most of this is in the productive stage as a consequence of technological lag, and scarce infrastructure, knowledge and investments in production (PROCISUR 2019).

and agriculture, the increase in these phenomena has impacted on agricultural productivity and the region's resilience. In turn, the increasing concentration of GHGs leads to higher air and sea temperatures and consequently provides conditions for pests and cross-border agricultural diseases to develop, which if not prevented in time can jeopardize the sanitary status of the countries and the region, which currently guarantees the commercialization of safe foods (PROCISUR 2019). These effects are aggravated by considerable genetic erosion in the agroecosystems of LAC, which is connected with the loss of native forests, diversity of species and biological life in the agricultural soil.

In this regard, it is necessary to strengthen R&D using conventional genetic breeding practices and the application of new technologies for the adaptation of crops to conditions of abiotic stress (extreme climate events) and biotic stress (emergence and re-emergence of pests and diseases), seeking a greater stability against extreme weather events.

Furthermore, climate variability, generated mainly by temperatures, humidity and rainfall higher than historic averages, has changed the behavior and the distribution of pests and diseases that affect agricultural production. Among other aspects identified is the resistance of certain weeds to the use of pesticides, the resistance of some insects to genetic events designed to control them, and the resistance of certain pathogens to the use of antimicrobials, far greater than natural resistance.

The study in the field of these behaviors, in addition to the use of satellite images and other digital technologies, permits the development of high-alert and risk management models, the study of local flora and fauna populations, among other opportunities. The development of monitoring, prevention and disease control practices and standards, and the integrated management of pests and biological control contributes to the health and safety of products and foods (Salles *et al.* 2009). The use of satellite images and drones allows data to be monitored remotely and in real time and helps to model crop cycles with the identification of critical crop threshold states, among other benefits, for which basic knowledge generated in the field and from S&T are required.

Soil and water management

The integrated management of soil, water, plants and nutrients is an urgent matter in the abovementioned processes of sustainable intensification and the degradation and scarcity of these resources in the world and specifically in LAC.

For over thirty years, R&D has turned precision agriculture into a tool that permits greater efficiency in the management of resources. It quantifies spatial and temporal variability, seeks to reduce the impact on the environment, improves working conditions, increases productivity and production quality and reduces food production costs (Bongiovanni *et al.* 2006). The new technologies, related to industry 4.0, such as Internet of Things systems with sensors of physicochemical variables, artificial intelligence, robotics, big data, drones, remote sensors, artificial vision systems, apps and software provide new spaces to broaden the benefits of a more intelligent management. Consequently, new knowledge must be generated by S&T. As well as these technologies, nuclear technologies also constitute a tool for defining strategies and developing sustainable practices that improve soil and water management.

The current crisis due to Covid-19 has intensified the labor shortage problem in the rural sector and it is expected that this will also impose higher standards throughout the food chain. The generation of capacities in the countries of LAC to optimize the use of these technologies in R&D and in regional cooperation will be a key element for the region to reassert itself in agriculture 4.0 and thus contribute to SDGs.

On soil management

Soil is essential for primary production and its health. It is the basis for guaranteeing nutritious, quality foods for animals and humans (95% of foods are produced in the soil). In LAC, 50% of cultivable soil is undergoing degradation processes; more than half of this is due to deforestation, and the rest is caused by changes in soil use and management, which generates erosion, loss of chemical, physical and biological fertility, contamination, and other issues (FAO *et al*. 2015). However, the application of conservation practices and no-till farming have resulted in a significant recovery of the soil used for extensive agriculture.

Soil involves various cycles and dynamics related to the mitigation of GHG emissions, through the sequestration of atmospheric carbon, the availability and quality of the water and nutrient cycles (Lal 2019). Keeping them healthy is vital for ecological sustainability, the resilience of food systems and food security in the countries of LAC.

R&D is required to stop and neutralize the impacts of soil loss and degradation, through more knowledge and scientific evidence on practices of restoration, regeneration, agroforestry systems and alternatives such as regenerative agriculture and the use of service crops, which make it possible to diversify systems, among other things.

On water management

The agricultural sector is the largest water user in the world. Agriculture accounts for 70% of all freshwater extractions globally (World Bank)[17]. Availability per person has been decreasing in recent years (over 20% in the last two decades at global level). An imminent increase is expected in competition for water resources. According to the FAO (2020b), it will be paramount to improve water management and prevent contamination of groundwater and scarcity, with the

(17) World Bank. Understanding poverty/Topics. Water in agriculture. https://www.bancomundial.org/es/topic/water-in-agriculture Accessed on 5 February 2021

support of effective governance and solid institutions to guarantee security and world nutrition and contribute to the fulfillment of the SDGs.

The attainment of varieties of crops resistant to water stress through conventional genetic breeding should remain a priority on the agenda of LAC countries. More recently, the application of the CRISP-Cas9 technique has shown its capacity to develop new productive and resistant varieties, which will be essential for satisfying greater food demand and the challenges of climate change in less time and at a lower cost (Merelo *et al.* 2019).[18]

Other R&D actions are related to the attainment of better agricultural practices for collecting and conserving water in dry areas and the application of increasingly modern and sustainable irrigation systems in irrigated areas. The variability that dry agriculture faces aggravates water disputes and unequal access, which particularly affects more vulnerable populations, family farming and poor rural populations, and demands appropriate practices and technologies, policies and governance to balance these forces. Irrigated agriculture, which provides 40% of the food produced in the world, represents 20% of total cultivated surface and is on average twice as productive by unit of land. This will play a fundamental role in the mitigation of climate vulnerability and diversification of crops.

Additionally, research is essential to sustain the improvement of instruments for fixing prices and assigning water, promote their efficient management and guarantee equitable and sustainable access (FAO 2020b).

3.2 Access and affordability

As the five ATs propose, it is not only a question of producing more but also ensuring access to foods for part of the population. Consumers should be able to access nutritious, safe high-quality foods, which are also in keeping with their cultures and consumption habits.

Agrifood S&T systems face the challenge of generating technologies, mainly for digital processing, to integrate stakeholders in food production, industry and logistics for diverse supply channels.

During the pandemic, lockdowns and restricted mobility made it possible to see and value the advantages of short trade circuits and of periurban production in all its diversity. In short supply circuits, the more direct contact increases the possibilities of knowing consumers' tastes and preferences and the economic

(18) One example is the obtaining of GE corn that is more productive than the original variety in drought conditions and similarly productive in normal conditions (Shi et al. 2017, cited by Merelo at al. 2019).

possibilities of affordability (Rodríguez *et al.* 2016). One challenge for the R&D+I system is to strengthen local economies through the generation of technologies and processes that adapt to this type of market strategy of proximity and which contributes to the traceability, safety and quality of foods, with social responsibility and with safety and hygiene regulations.

In turn, e-commerce has been one of the alternatives most used by family farmers in these times and its use is attractive to young people.

Furthermore, large urban concentrations mobilize large volumes of food, which on occasions comes from regional economies and is then transported over long distances. Other actors intervene who may be local, national or multinational, for which they use other resources apart from those used for production intended for short circuits of proximity.

Commercialization conditions and limitations are very different between large supply chains and local ones. Different sectors of the population are involved who require different knowledge and public policies to generate a synergy-driven supply network.

In turn, consumption trends have varied notably in recent times, with a greater involvement by consumers in the choice of foods. This incorporates research with other multidisciplinary approaches that have still not been sufficiently addressed by the S&T system of LAC countries, studies into consumption and the subsequent adaptations in all the stages of production and elaboration of foods, as well as systems of traceability, friendlier environmental management, certification systems with citizen participation, food labels, use of circular economy techniques, among others. Similarly, it is important to communicate more and better about the comparative advantages of the region in producing nutritional foods, considering good environmental management and protection based on scientific evidence.

Regarding affordability, greater knowledge is needed on price formation related to cultural identity and social conditions that influence the choice of foods and social aspects.

3.3 Nutritional quality and health

Considering the five ATs and some of the SDGs, such as SDG 2 Zero Hunger, the agrifood R&D agenda must orientate scientific, technological and innovative contributions to address aspects that contribute to the concept of "One Health," such as the production of nutritional food for a healthy diet and the protection of human and animal health, which is more urgent now as a consequence of the Covid-19 pandemic.

In this regard, R&D must align forces with the agrifood industry which, as Le Vallée et al. argue (2018), has been evolving technologically and organizationally towards a digital era of smart manufacture (Industry 4.0), which will use the Internet of Things, artificial intelligence, big data and will be connected in the cloud. These technologies help to provide relevant and timely information on products and foods themselves (healthy, safe, delicious and nutritious), on the way in which they are produced and delivered (sustainable, traceable and reliable) and on preferences and changes in consumption.

In relation to nutritional quality, techniques such as gene editing (GE) have the potential to modify relatively quickly the chemical or nutritional makeup of food products, as well as crops, fungi and animals.[19]In clonal propagation crops such as potato[20], banana, yucca, sugarcane or vine, among others, the use of GE makes it possible to make specific improvements on elite genotypes. In animal species, marked increases can be obtained in productive efficiency, resistance to diseases and greater nutritional quality (Feingold et al. 2017). This technique can be applied in traditional crops and basic food staples, but it is also an opportunity for less common crops and animal species (Salles *et al.* 2019). Melero et al (2019) highlight the potential of the technique to accelerate plant domestication processes, which contributes to preserving biodiversity.

In turn, the appearance of new consumers who demand foods with direct contributions to health and the need of companies to invest in the development of new foods that come from biodiversity have motivated in the region the development of functional foods, and efforts to establish healthy attributes through validated experimental methods (Descalzo et al. 2012).

Once again, GE offers many different opportunities. Examples of this are the generation of a variety of rice with a 10% higher proportion of amylose, which helps to prevent serious infections and to reduce the glycemic index (Melero *et al.* 2019)[21].

Another example is the production of animals that produce milk with a greater proportion of conjugated linoleic acid and of proteins beneficial for human health, or which inhibits the secretion of allergenic proteins such as beta-lactoglobulin (Feingold *et al.* 2017). Dairy products play an important role in this context (IICA 2020a), but it is also necessary to advance R&D in other raw materials with possibilities for adding value and becoming integrated to the agroindustrial complexes, analyzing the opportunities of niche markets.

(19) In the Southern Cone plant research groups are working on fruit species such as Vitis and Prunus at INIA-Chile, Citrus at INIA-Uruguay, potato at INTA-Argentina and INIA-Chile, soya in INIA-Uruguay and EMBRAPA-Brazil, sugarcane and alfalfa at INTA-Argentina and Setaria at EMPRABA-Brazil. In animals there are teams with projects to obtain better quality milk at INTA-Argentina and to increase muscle mass in bovines at EMBRAPA-Brazil (Feingold 2017).

(20) INTA Argentina is working on the nutritional and industrial quality of the potato with genes to be edited or edited directly related with enzymatic browning and cold-induced sweetening.

(21) In reference to the work done by the team of Sun et al. 2017.

Foods from organic agriculture and from agroecology, considered by consumers to be healthier foods, are configured as an excellent market opportunity for a group of producers, but require more knowledge. The R&D must continue to develop procedures and protocols for monitoring and control of production processes, practices and standards of monitoring, prevention and pest and disease control, the integrated management of pests and biological control (Salles *et al.* 2009) and research into the productivity and profitability of the systems and into consumers' perceptions regarding tastes and flavors. Spaces of dialogue are required between more "urban" visions and producers' visions on ways of producing, in order to generate knowledge for decision-making.

The possibility of providing segmented consumption (for babies, for adults, for sportspeople, for celiac sufferers, among others) is an opportunity that has been explored very little in Latin America.

Furthermore, the R&D must go further in studies into the impacts of agriculture and livestock on human health and diseases associated with foods, both with regards to consumer health and that of the producer.

4

Final reflections

Focusing R&D on food systems, where it is no longer the case that what is produced is consumed, but rather what is consumed is produced, implies major opportunities for the LAC region. In this vein, the region must work towards bridging the major gaps that countries present in productivity. The options that the current scientific and technological scenario offers include the use of new technologies for genetic breeding such as gene editing, applications of robot technologies, drones, sensors, artificial intelligence, Internet of Things, big data, and a more holistic vision of agroecosystems. Each of these challenges and opportunities identified for agrifood R&D in the countries of LAC can be addressed by applying new technologies and fully leveraging the benefits they provide.

In order to tackle pre- and post-Covid-19 threats and thus harness the opportunities mentioned, strategic decisions are required to ensure the necessary investment in R&D—currently dramatically below the levels of other areas of the world—and improve the performance of R&D institutions and of the whole innovation system in the region. To do so, it is essential to review the current institutional models, not only to strengthen capacities in new fields of knowledge and emergent technologies, but also so that producers acquire the skills to harness them effectively. R&D

must generate knowledge and place it in context to empower producers with the changes that are required to make food systems more sustainable. These efforts are of considerable importance in smaller countries, which lack specialist endogenous capacities to address these tasks or which present economies that have deteriorated considerably because of the pandemic.

It is essential to make institutional commitments to incorporate the perspective of gender, youth and indigenous peoples, in order to encourage a greater participation that enriches the ensemble of visions, knowledge and strategies for technological development (Bello *et al.* 2021). It is also essential to recover tacit knowledge in local communities to restore the value of their contribution, their wisdom and their practices in the construction of innovative solutions, acknowledging the great diversity of cultures and existing production systems in the region.

The management of these transformations requires the presence of the states in the rural territory, both through R&D systems and extension and policies that create a stable institutional environment and infrastructure suitable for innovation. Integration between the S&T system and the political system is an essential condition for the promotion of sustainable and equitable development. It is imperative to generate evidence that sustains decision-making, maximizes its results and minimizes the costs of implementation of public policies that foster competitive and inclusive innovation (Arias *et al.* 2021). What is needed are better policies, more innovation, greater investment and inclusion to consolidate agricultural systems and productive and resilient foods. Furthermore, the governance model of the R&D+I agrifood system of the countries of LAC must stimulate greater participation from the private sector, businesses, foundations, universities and agricultural and rural communities, and must also integrate into the environment of political technical decision-making, not only through the ministries directly related to the sector, but also with health, economy and environment ministries. And as FONTAGRO (2019:12) argues, "all this from an approach not of rivalry, but of synergies between public and private efforts".

The LAC region is a great contributor to global food security and its production platform is built on agrifood R&D advances in the sustainability of its productive sectors. The agricultural sector has a key role to play in the transformation of food systems and, in this regard, the current S&T scenario constitutes a very potent instrument for the fulfillment of SDGs.

The question remains of whether institutional, financial and human resources in the region and the current processes of organizational and policy changes will be sufficient to harness these opportunities. Cooperation between countries is essential, as is a robust and solvent institutional framework around R&D systems. The pandemic has reinforced the importance of collaborative work and of a regional and hemispheric institutional framework.

The way in which high-impact knowledge and technologies are generated through innovation must aim at collaborative work, through public-private partnerships, multi- and transdisciplinary approaches, and the participation of economy actors outside of the sector. As FAO *et al* (2020) argue, the crisis generated by Covid-19 has also opened up a number of opportunities to transform the primary production, sustainability and resilience of the agrifood sector of these countries. Harnessing these opportunities will depend on the ability of the region to work collectively.

5

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