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Socio-economic evaluation of sunflower agri-food chains in Brazil in view of the potential implementation of innovative plant protein ingredients for human consumption

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ABSTRACT

Ensuring a sustainable global food supply in a scenario of shrinking natural resources, and a rising global population and wealth is one of the major challenges currently facing society. In this context, the replacement of animal protein by plant protein in human nutrition is seen as one possible way of achieving more sustainable global agri-food systems. Presently, soybean leads the market segment of plant protein ingredients. However, the growing use of genetically modified (GM) soybeans coupled with the increasingly negative image of GM food among consumers, particularly in Europe, have led food manufacturers looking for alternative plant protein sources to soybean. In this regard, sunflower emerges as a promising raw material for high-quality plant protein ingredients, and the implementation of innovative sunflower products in Brazil could promote more sustainable food and agricultural production, due to the potential for sunflower cultivation on existing agricultural areas in Brazil. Although the food industry and food research institutes lead the development of plant protein food innovations, the implementation of such innovations requires a holistic agri-food chain approach. Thus, it should be preceded by the analysis of the agri-food chain to which the innovation is related, especially for food innovations related to new or non-established crops. Against this background, this study aimed at performing a socio-economic analysis of an agri-food chain focused on a non-established crop in view of the potential implementation of food innovations, using sunflower agri-food chains in Brazil and upcoming sunflower high-quality food protein ingredients as a case study. Thus, fieldwork was carried out in the main sunflower-producing areas between April and August 2016 for data collection among sunflower chain agents from the input, farming, and processing segments, besides representatives from the research sector. Section 1 applied a multiple case study embedded design to describe and analyze the dynamics of operation of sunflower agri-food chains in Brazil. The analysis followed a theory-driven approach based on concepts from transaction costs economics and the social network approach. The findings indicated an environment of high transaction costs, in which the economic transactions are ruled by formal and relational governance structures, and made possible through knowledge diffusion, under the coordination of a processing company. Nevertheless, the sustainable long-term operation of the sunflower chains is constrained by typical limitations of non-established crops, such as restricted market structure, land use competition with well-established crops, and technological limitations regarding plant breeding, and control of pests and diseases.

Moreover, Section 1 revealed that a farmer-led sunflower chain in the state of Mato Grosso (MT) stood out regarding the operational stability, suggesting a closer analysis of this farmers' collective endeavor, which was performed in the subsequent section. Thus, Section 2 adopted a single case study embedded design to describe and analyze the establishment process of the leading Brazilian sunflower agri-food chain located in MT under the regime of farmers. The analysis followed a framework that regarded the agri-food chain establishment as an entrepreneurial process. The findings indicated that the process of establishment of this sunflower chain has been a complex social-economic endeavor stemming from a set of interconnected driving forces composed of entrepreneurial skills, social network, resource availability, and crop suitability. Furthermore, Section 2 suggested the existence of a supportive institutional environment for the establishment of new sunflower agri-food chains in MT among soybean farmers, besides indicating the need of examining the potential for sunflower production expansion in MT, which was the focus of the next section. Thus, Section 3 applied an integrated assessment approach that combines an agent-based model (ABM) with a crop growth model to investigate the potential for sunflower land use expansion in double-cropping systems prevailing in MT. The ABM was implemented using the software package Mathematical Programming-based Multi-Agent Systems (MPMAS), and the crop yields simulations were implemented using the process-based model for nitrogen and carbon in agro-ecosystems (MONICA). The findings indicated the existence of a potential for the expansion of the sunflower production in MT. Nevertheless, this potential is constrained by the distance between the producing areas and the processing facilities. Moreover, the simulations confirmed the land use competition between sunflower and maize, showing that sunflower land use is strongly associated with agents' expectations regarding prices and yields of sunflower and maize. However, the results also revealed a complementary effect between these two crops due to the different water deficit tolerance of these crops. Section 3 also highlighted that the simulated potential production of sunflower would require further increases in the current processing capacity installed in MT. To conclude, the analyses performed in Sections 1, 2, and 3 indicated relevant aspects to be considered by innovators interested in implementing food innovations related to non-established crops. The scarcity of feedstock suppliers requires the adoption of contractual and relational governance structures coupled with the provision of technical assistance at the farming level. Moreover, farmers with recognized professional and social reputation as well as leadership abilities play an important role in influencing other farmers to adopt a non-established crop. Finally, the suitability of the crop for the agricultural system prevailing in the region is essential for ensuring a minimum level of farmers' willingness to adopt a non-established crop. In this regard, particular attention should be given to the land use competition with well-established crops.

Sozio-ökonomische Bewertung von agrarischen Sonnenblumenwertschöpfungsketten in Brasilien im Hinblick auf eine mögliche Einführung innovativer Pflanzenproteine für die Humanernährung

Zusammenfassung: Die nachhaltige Sicherstellung einer weltweiten Lebensmittelversorgung im Umfeld abnehmender natürlicher Ressourcen bei zunehmender Weltbevölkerung und wachsendem Wohlstand ist eine der großen Herausforderungen der Menschheit. Vor diesem Hintergrund wird der Ersatz tierischen durch pflanzliches Protein in der menschlichen Ernährung als ein möglicher Weg gesehen, um weltweit nachhaltigere Agrar- und Lebensmittelsysteme zu etablieren. Momentan dominiert Soja das Marktsegment für pflanzliche Proteininhaltsstoffe. Allerdings hat die zunehmende Verwendung von gentechnisch verändertem (GV) Soja in Verbindung mit einem sich insbesondere seitens europäischer Konsumenten verstärkt negativ darstellenden Image von GV Produkten unter Lebensmittelherstellern eine Suche nach alternativen Quellen von pflanzlichen Proteinen anstelle von Soja ausgelöst. Aus diesem Grund tut sich die Sonnenblume als ein vielversprechendes Material für pflanzliche Proteininhaltsstoffe hoher Qualität hervor. Auch könnte die Implementierung von innovativen Sonnenblumenprodukten in Brasilien eine nachhaltigere Lebensmittel- und Pflanzenproduktion fördern, da der Anbau von Sonnenblumen auf bestehenden Ackerflächen Brasiliens möglich ist. Obwohl die Lebensmittelindustrie und die institutionelle Lebensmittelforschung die Entwicklung von Innovationen im Bereich der Lebensmittel auf Basis pflanzlicher Proteine vorantreiben, ist für die Implementierung solcher Innovationen ein ganzheitlicher Blick auf die Agrar- und Lebensmittelkette erforderlich. Aus diesem Grund sollte einer Implementierung von Innovationen in diesem Bereich die Analyse der Agrar- und Lebensmittelkette vorausgehen, insbesondere im Bereich von Nahrungsmittelinnovationen mit Bezug zu neuen oder nicht etablierten Feldfrüchten. Vor diesem Hintergrund zielt die vorliegende Arbeit auf die Durchführung einer sozio-ökonomischen Analyse einer Agrar- und Lebensmittelkette unter Fokussierung auf eine nicht etablierte Feldfrucht und im Hinblick auf die potenzielle Implementierung von Lebensmittelinnovationen. Zu diesem Zweck werden die Agrar- und Lebensmittelkette der Sonnenblume in Brasilien und in der Entwicklung befindliche hochqualitative Proteininhaltsstoffe auf Basis dieser Pflanze als Fallstudie betrachtet. Es wurden Feldstudien in den brasilianischen Hauptanbaugebieten der Sonnenblume von April bis August 2016 durchgeführt, die der Gewinnung von Daten durch Befragungen unter Akteuren der Sonnenblumenwertschöpfungskette (Landhandel, Anbau und Verarbeitung)

sowie Vertretern von Forschungsinstituten dienten. Abschnitt 1 verwendet als Untersuchungsmethode einen mehrfachen Fallstudienansatz, um die Funktionsdynamik der agrarischen Sonnenblumenwertschöpfungsketten in Brasilien zu beschreiben und zu analysieren. Die Analyse folgte einem auf der Theorie der Transaktionskosten und der Theorie von sozialen Netzwerken basierenden Ansatz. Die Ergebnisse zeigen ein Umfeld hoher Transaktionskosten, in welchem die Transaktionen von formalen und beziehungsgebundenen Governancestrukturen beherrscht werden, hervorgerufen durch Wissensdiffusion unter dem koordinierenden Einfluss eines verarbeitenden Unternehmens. Dennoch ist eine dauerhaft nachhaltige Funktion von Sonnenblumenwertschöpfungsketten, wie für nicht etablierte Feldfrüchte typisch, eingeschränkt: dies wird bedingt durch eine begrenzte Marktstruktur, Landnutzungskonkurrenzen mit gut etablierten Feldfrüchten und technologische Limitierungen im Hinblick auf die Pflanzenzucht sowie den Pflanzenschutz. Darüber hinaus zeigt Abschnitt 1, dass eine durch die Landwirte selbst organisierte Sonnenblumenwertschöpfungskette im Bundesstaat Mato Grosso (MT) sich durch ihre funktionale Stabilität hervortut. Hier empfiehlt sich eine genauere Untersuchung dieser kollektiven Bemühungen der Landwirte, die im nachfolgenden Abschnitt angegangen wird. Entsprechend wird in Abschnitt 2 ein einfacher Fallstudienansatz gewählt, um den Entstehungsprozess der prominentesten Sonnenblumenwertschöpfungskette Brasiliens, ansässig in MT und organisiert von Landwirten, zu beschreiben und zu analysieren. Dabei folgt die Analyse der Vorstellung, dass die Entstehung der agrarischen Lebensmittelwertschöpfungskette einem unternehmerischen Prozess entspricht. Die Ergebnisse zeigen, dass der Entstehungsprozess dieser Sonnenblumenwertschöpfungskette einer komplexen sozio-ökonomischen Anstrengung entspringt, resultierend aus einer Mischung untereinander verbundener Antriebe: unternehmerischer Kompetenzen, sozialer Netzwerke, vorhandener Ressourcen und passender Feldfrüchte. Im weiteren Verlauf deutet Abschnitt 2 die Existenz eines unterstützenden institutionellen Umfelds für die Etablierung neuer Sonnenblumenwertschöpfungsketten in MT unter den Landwirten an, die bislang Soja anbauen. Das Potenzial der Ausweitung des Sonnenblumenanbaus tritt hierbei in den Fokus des nächsten Abschnitts. Abschnitt 3 nutzt den Ansatz einer integrierten Abschätzung und kombiniert hierzu ein Agenten-basiertes Modell (ABM) mit einem Pflanzenwachstumsmodell, um das Potenzial der Anbauflächenausweitung für Sonnenblumen in den vorherrschenden Zweifruchtsystemen in MT zu untersuchen. Das ABM wurde mithilfe der Software „Mathematical Programming-based Multi-Agent Systems“ (MPMAS) umgesetzt, die Ertragssimulation erfolgte mittels des prozessbasierten „Models for nitrogen and carbon in agro-ecoystems“ (MONICA). Die Ergebnisse zeigen ein Potenzial der Produktionsausweitung von Sonnenblumen in MT an. Jedoch ist dieses Potenzial limitiert durch die Entfernungen zwischen Anbaugebieten und Verarbeitungsstätten. Darüber hinaus bestätigen die Simulationen die Landnutzungskonkurrenzen zwischen Sonnenblumen und Mais: es besteht ein starker Zusammenhang der Akteure im Hinblick auf erwartete Preise und Erträge dieser Feldfrüchte. Allerdings zeigen die Ergebnisse auch, dass ein komplementärer Effekt zwischen Sonnenblumen und Mais besteht, da unterschiedliche Toleranzen gegenüber Trockenstress existieren. Abschnitt 3 zeigt zudem, dass das simulierte Potenzial der Anbauausweitung von Sonnenblumen einen Ausbau der aktuell vorhandenen Verarbeitungskapazität in MT bedarf. Zusammenfassend beschreiben die Analysen der Abschnitte 1, 2 und 3 die von gestaltenden Akteuren zu beachtenden Aspekte, wenn Lebensmittelinnovationen durch nicht etablierte Feldfrüchte erfolgen sollen. Die Knappheit an Rohstofflieferanten erfordert den Einsatz vertraglicher und beziehungsgebundener Governancestrukturen, verknüpft mit der Bereitstellung technischer Unterstützung für die landwirtschaftliche Erzeugung. Zudem spielen Landwirte mit hoher Professionalität, sozialer Reputation und Führungsqualitäten eine wichtige Rolle im Einwirken auf andere Landwirte bezüglich des Anbaus von nicht etablierten Feldfrüchten. Schließlich ist die grundsätzliche Eignung dieser Feldfrüchte für das regional vorherrschende Anbausystem unverzichtbar, um ein Mindestmaß an Anbaubereitschaft für nicht etablierte Früchte bei den Landwirten sicherzustellen. In dieser Hinsicht ist besondere Aufmerksamkeit bezüglich der Landnutzungskonkurrenzen mit gut etablierten Feldfrüchten angezeigt.

INTRODUCTION

1 Research background

1.1 Food innovations and the need for an agri-food chain approach

The implementation of food innovations is a multidimensional process due to the manifold aspects of agri-food chains. An agri-food chain involves social, economic, technological, environmental, and institutional aspects related to interdependent agents and organizations from different chain segments (inputs, farming, processing, and distribution), ruled by governance structures, and that seeks to attend consumers' demands for plant or animal food products. Thus, an agri-food chain is subjected to the principles of interdependency, propagation, feedback, and synergy applied for systematic approaches (Silva and Souza Filho, 2007), and thereby the implementation of food innovations requires a holistic agri-food chain approach (Zilberman et al., 2017).

Agri-food innovations include new products, new technical and managerial processes, new locations for producing existing products, and new institutions for organizing supply chains (Zilberman et al., 2017). These innovations are induced by technological development in the food industry, and by structural and behavioral change on the demand side (Du et al., 2016). The development of plant protein food ingredients is an example of food innovations driven by factors from both supply and demand sides, including (1) the growth in population (2-billion over the next four decades) and in income, which is projected to double the global food demand, particularly for proteins (FAO, 2013; Aiking, 2014), (2) the greater use of natural resources as well as the higher levels of emissions of waste and greenhouse gases (GHGs) from livestock in comparison with plant production (Poore and Nemecek, 2018; Sabaté and Soret, 2014), (3) consumers' ethical concerns on animal welfare (Vainio et al., 2016), and (4) the lower feedstock cost incurred in the production of plant protein compared to the production of animal protein ingredients – in order words, the cost competitiveness of plant protein (Frost & Sullivan, 2012).

The development of new technologies for the production of plant protein food ingredients has been led by the food industry and food research institutes (Wu et al., 2014; Frost & Sullivan, 2012; González-Pérez and Vereijken, 2007). Nevertheless, the successful implementation of food innovations depends on other agri-food chain agents with whom the innovator (usually a food company) transacts, and requires from the innovator to carry out agri-food chain adjustments – upstream (in the firm's input procurement arrangements and production technology), midstream (in its processing technology), and/or downstream (in its marketing arrangements based on the nature of the innovation) (Du et al., 2016).

Therefore, the implementation of food innovations, especially those related to new or non-established crops, should be preceded by an analysis of the agri-food chain to which the innovation is related. Three relevant aspects to be considered in this analysis are: (1) the understanding of the dynamics of operation of the agri-food chain, (2) the investigation of its establishment process, and (3) the examination of crop adoption and diffusion among farmers from the feedstock supply region.

Understanding the dynamics of operation of an agri-food chain provides to the innovator relevant knowledge to ensure the implementation of the food innovation since it involves the analysis of the governance structures adopted by the agri-food chain actors to promote and organize the economic activities established in the chain. The governance structures provide incentives, sanctions, and information to promote a particular type of behavior (e.g., the participation of farmers as feedstock suppliers) (Dorward and Omamo, 2009). In this regard, both formal and relational governance structures are considered determinants for the operation of agri-food chains (Trienekens et al., 2014; Trienekens, 2011). Thus, considering that social relations underpin economic transactions, the transaction cost economics (Williamson, 1979; Williamson, 1985; Williamson, 1996) and the social network approach (Granovetter, 1985; Uzzi, 1997; Granovetter, 2005) provide complementary theoretical foundations for analyzing the functioning of social-economic systems, as indicated by several studies on agri-food chains (Gërdoçi et al., 2016b; Gërdoçi et al., 2016a; Chagomoka et al., 2014; Zander and Beske, 2014; Trienekens, 2011; Martino, 2010; Zhang and Aramyan, 2009; Fritz and Fischer, 2007).

Investigating the establishment of an agri-food chain focus of an innovation also provides valuable information to the innovator, especially if the expansion of the agri-food chain is required to ensure the implementation of the innovation. Despite the large number of agri-food chain studies in different research areas, such as agricultural economics (e.g., Du et al., 2016; Zilberman et al., 2017), supply chain management (e.g., Mena et al., 2013; Matopoulos et al., 2007), and rural development (e.g., Rosairo and Potts, 2016; Chagomoka et al., 2014), the analysis of the establishment process of agri-food chains is a seemingly under-researched issue (Donovan et al., 2015). In other words, analyzing how an agri-food chain is formed, moving from the "non-established chain" to the "established chain" status. In this regard, the entrepreneurial approach seems particularly suitable for this analysis, once the research field of entrepreneurship is fundamentally concerned with understanding how economic activities come into existence (Venkataraman, 1997). Moreover, entrepreneurship is defined as a process that includes the discovery, enactment, evaluation, and exploitation of opportunities to create future goods and services (Guterman, 2015). Thus, the model of the entrepreneurial process (Bygrave, 2010) provides an appealing foundation for the analysis of the establishment of an agri-food chain.

Finally, examining crop adoption and diffusion among farmers from the feedstock supply region is another crucial aspect to be considered by the innovator before implementing the food innovation, especially when the innovation is related to a new or non-established crop. Thus, the availability of feedstock is one of the main drivers for the innovator's decision on which agri-food chain design to adopt regarding the scale of the operation, how much of the feedstock should be produced in-house or purchased from suppliers, and which governance structure should be adopted to rule the farmer-processor transactions (Zilberman et al., 2017; Du et al., 2016). In this regard, the bio-economic modeling approach constitutes a valuable tool to analyze the crop adoption and diffusion, since it enables the simulation of farm-level decision-making regarding land use allocation taking into account typical socio-economic, technological, and biological aspects of the agricultural systems from a region of interest (Hampf et al., 2018; Carauta et al., 2018).

1.2 Sunflower high-quality food protein ingredients

The replacement of animal protein by plant protein in human nutrition is seen as one possible way of achieving a more sustainable agri-food system, being a trend in the global food market (Aiking, 2014; Sabaté and Soret, 2014; Vainio et al., 2016). Currently, soybean is the major worldwide source of plant protein (USDA, 2018) with the widest range of applications in the food industry (Frost & Sullivan, 2012; González-Pérez and Vereijken, 2007). The leadership of soybean in the market of plant protein ingredients is mainly explained by the greater marketing power of soy protein ingredient manufacturers, besides the higher global production of soybean compared to other plant protein sources (Frost & Sullivan, 2012). Nevertheless, despite the lack of scientific consensus (Zilberman et al., 2018), soy proteins have a negative image in Europe due to being genetically modified (GM) (Frost & Sullivan, 2012), leading food manufacturers looking for alternative plant protein sources to soybean (Pickardt et al., 2015).

Other plant protein sources include wheat and pea, the two most consolidated plant protein feedstock after soybean, and several emerging raw materials like canola, rice, potato, chia, lupin, peanut, and sunflower (Pojić et al., 2018; Lucas et al., 2015; Joshi and Kumar, 2015; Frost & Sullivan, 2012). In this second group, sunflower emerges as a promising raw material for the production of high-quality plant proteins ingredients due to factors such as (1) agro-climatic suitability to be grown in different regions of the world, (2) high protein content (40-50% in the sunflower meal), (3) low level of anti-nutritive compounds, (4) high intrinsic solubility, which is a prerequisite for many functional properties, and (5) absence of toxic substances (Pickardt et al., 2015; González-Pérez and Vereijken, 2007; González-Pérez et al., 2002; Weisz et al., 2009).

On this background, the research project "Sustainable cultivation and novel processing of sunflower seeds for simultaneous production of sunflower oil, solid fuel, and protein-rich food ingredients" (SunflowerProtein) has been initiated. The project involved several partners from German and Brazilian institutions within a holistic agri-food chain approach, encompassing (1) agriculture/primary production, (2) processing/production of food ingredients, (3) application of the products to prove their market potential, and (4) a socio-economic analysis of the sunflower sector in Brazil to which the present study is directly related.

SunflowerProtein aimed to promote the total use and fractionation of the sunflower seeds and the integral use of all fractions by the provision of high-quality protein ingredients and oil, besides hulls and sugars for energetic and technical use. Furthermore, the research project sought to evaluate the cultivation of sunflower as an additional crop on existing agricultural areas and the potential for the development of high-quality sunflower food protein ingredients in Brazil. The overall SunflowerProtein concept considers that innovations in process technologies and the development of new products with higher added value can promote more sustainable food and agricultural production.

Thus, based on the technological possibilities for high-quality sunflower food protein ingredients and the demand for plant protein in the food ingredient market, the Fraunhofer Institute for Process Engineering and Packaging developed a process to recover food grade proteins from sunflower. This technology enables the fractionation of sunflower seeds starting with a complete de-hulling of the seeds, which facilitates the recovery of high-quality protein meals and concentrates suitable for human consumption instead of the low-value residues from conventional de-oiling destined to animal feed (Figure 1). This innovative sunflower processing technology constituted the principal motivation for the SunflowerProtein research project.

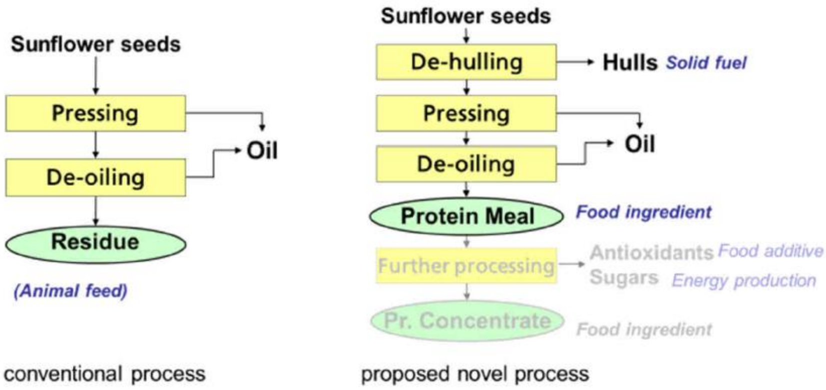


Figure 1. Conventional and novel sunflower processing

1.3 Characterization of the production and processing of sunflower in Brazil

The participation of Brazil in the SunflowerProtein project stems from its prominent position as a worldwide agricultural supplier and the existing potential for expanding the sunflower production into existing agricultural land in double cropping systems. This agricultural production system enables the cultivation of more than one crop in the same area in one agricultural year, resulting in two growing seasons per year. Double cropping systems contribute to increasing farms' income by additional revenues, and the optimization of farms' production resources (land, agricultural inputs, machinery, infrastructure, and labor), besides reducing the exposure to market and climatic risks (Carauta et al., 2017; Pires et al., 2016). Additionally, the adoption of double cropping systems along with technological improvements (e.g., plant breeding, and plant pest or disease control) have led to the intensification of the agricultural production in Brazil whilst reducing the pressure for agricultural land expansion (Pires et al., 2016). For instance, while the grain production in Brazil increased by 107% from 2005 to 2017, the cultivated area expanded by 24% in the same period. Therefore, the production increase was mostly due to gains in yields (in the order of 67%), and the increased adoption of double cropping systems, especially the succession soybean-maize, since the cultivated area of maize in the second growing season increase by 240% from 2005 to 2017 (CONAB, 2018)

Currently, the sunflower cropping area is incipient in Brazil, with a maximum planted area of 145,700 ha in 2014 (CONAB, 2018). Nevertheless, the country shows potential for expanding its sunflower producing area mainly due to the suitability of sunflower to be grown after the harvest of soybean in the second growing season, particularly in the state of Mato Grosso (MT), which leads the national production of soybean and sunflower (Figure 2).

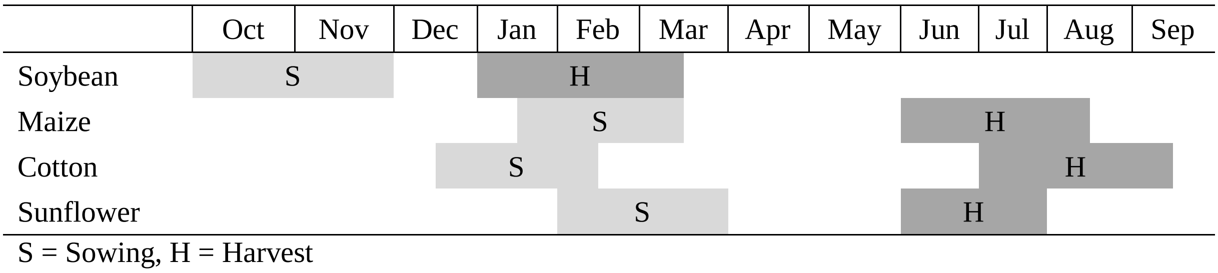


Figure 2. Agricultural calendar in the state of Mato Grosso

The cultivated area of soybean in MT (9.3 million ha in 2017) (CONAB, 2018) indicates the enormous potential for an extension of the sunflower cultivation. Furthermore, the introduction of sunflower in double cropping systems has been recently regarded as a mean to enhance the sustainability of agricultural production systems in Brazil due to the following aspects. Sunflower farming takes place in existing grain producing areas mostly between February and July when the weather conditions are less favorable to the infection with *Sclerotinia sclerotiorum*, a harmful pathogen common to sunflower and soybean (Castro and Leite, 2018). Moreover, sunflower can contribute to the management of certain nematodes infestation, which is a severe problem in grain producing areas in Brazil, besides providing a viable additional farm income source, different from other non-commercial alternative cover crops available for farmers, such as millet, *Crotalaria spectabilis*, and *C. ochroleuca* (Dias et al., 2016). Finally, sunflower cultivation in succession to soybean reduces environmental impacts related to human toxicity, freshwater toxicity, freshwater eutrophication, climate change, and terrestrial acidification impacts in comparison to monoculture systems, due to crop diversification, land use intensification, and synergies with soybean and maize that leads to the more efficient usage of production factors available in the farm (Matsuura et al., 2017).

Presently, the sunflower sector is a small agricultural sector in Brazil. Although the farming and processing of sunflower in Brazil date from the early 1900's, only from the late-1990s they have increased due to better technical and commercial conditions for sunflower production (Castro and Leite, 2018). Nevertheless, the sunflower planted area is still small in Brazil (Table 1). In the growing season 2016/17, it represented less than one percent of the world production led by Russia and Ukraine, and only three percent of Argentina's production area, which leads the sunflower production in South America.

Table 1. Sunflower cultivated area (in 1000 ha) per countries from growing seasons 2007/08 to 2016/17

Country	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Russia	5,000	6,000	5,600	5,550	7,200	6,125	6,795	6,371	6,454	7,175
Ukraine	3,400	4,500	5,000	5,400	5,400	5,500	5,300	5,300	5,500	6,400
European Union	3,343	3,788	3,920	3,747	4,283	4,291	4,617	4,291	4,171	4,130
Argentina	2,569	1,820	1,495	1,743	1,823	1,623	1,260	1,440	1,270	1,715
China	719	964	959	984	940	889	923	949	1,036	1,153
Brazil	111	75	71	66	75	70	146	112	51	63
Others	6,199	6,745	5,922	5,592	4,899	5,106	4,982	4,640	4,776	4,672
World	21,341	23,892	22,967	23,082	24,620	23,604	24,023	23,103	23,258	25,308

Source: (USDA, 2018)

Internally, three regions in the states of Mato Grosso (MT), Goiás (GO), Minas Gerais (MG), and Rio Grande do Sul (RS) concentrate the sunflower production (Figure 3). Since 2008, these four states have accounted for at least 90% of the Brazilian sunflower planted area that varied between 51,500 ha in 2016 and 145,700 ha in 2014 (Table 2). Comparatively, the sunflower producing area represents less than one percent of the planted areas of soybean and maize (CONAB, 2018).

Table 2. Sunflower cultivated area (in 1000 ha) per states in Brazil from 2008 to 2017

Country	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
MT	60.4	41.3	40.6	39.9	47.1	50.7	126.2	86.4	25.6	31.8
GO	21.7	3.5	11.4	6.3	13.9	3.6	4.2	7.4	14.0	16.6
MG	-	-	-	5.4	4.3	11.0	11.3	14.0	7.0	9.3
RS	18.4	23.6	13.1	7.9	3.3	2.7	3.3	3.3	3.3	3.3
Others	10.8	6.6	5.9	6.9	5.9	2.1	0.7	0.4	1.6	1.7
Brazil	111.3	75.0	71.0	66.4	74.5	70.1	145.7	111.5	51.5	62.7

Source:(CONAB, 2018)

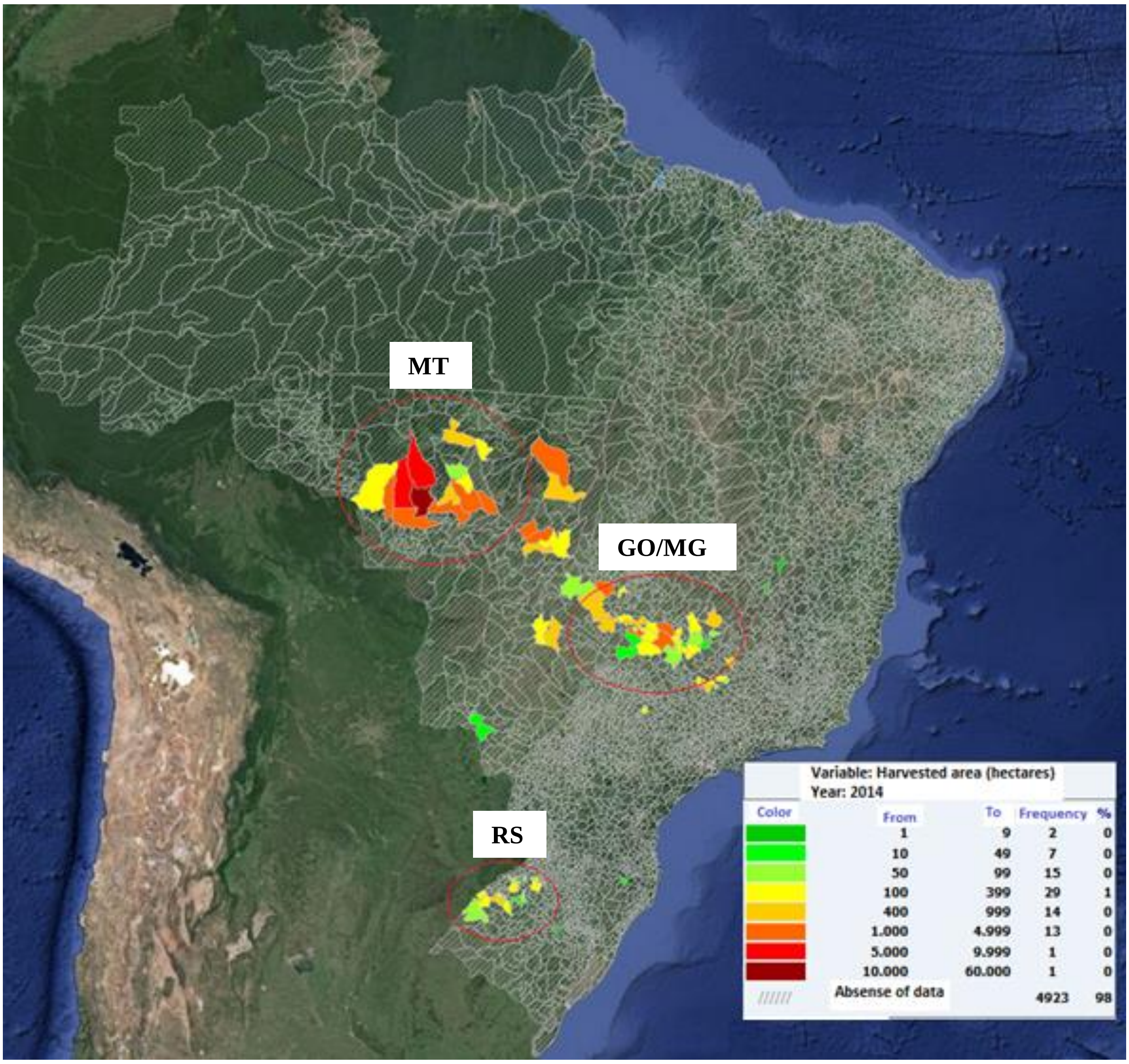


Figure 3. Geographical distribution of sunflower cultivation in Brazil in 2014

Source: (IBGE, 2018)

The three areas in MT, GO/MG, and RS also concentrate the processing of sunflower in Brazil. The main destination of sunflower production is the food segment market of edible vegetal oil, which is led by the soybean oil. A comparison between production, consumption, and imports of sunflower and soybean oils provides an idea of the differences regarding the size of these two food market segments, and highlight the niche market status of sunflower oil in Brazil (Table 3). Over the last ten years, the average annual domestic consumption of sunflower oil in Brazil was 74 metric tons against 5,425 metric tons of soybean oil. Furthermore, while Brazil is self-sufficient in soybean oil production, the annual sunflower oil imports have on average accounted for approximately 40% of its domestic consumption over the same period.

Table 3. Production, consumption, and imports of sunflower and soybean oils (in 1000 tons) in Brazil from growing seasons 2007/08 to 2016/17

	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Sunflower oil										
Production	48	48	35	32	46	44	88	58	27	42
Consumption	59	65	64	65	85	70	107	82	64	75
Imports	18	17	30	34	40	27	29	26	27	43
Soybean oil										
Production	6,160	6,120	6,470	6,970	7,310	6,760	7,074	7,759	7,627	7,850
Consumption	3,955	4,275	4,980	5,205	5,390	5,534	5,705	6,265	6,330	6,610
Imports	67	6	37	0	0	6	0	11	65	60

Source: (USDA, 2018)

Currently, four agri-food chains operate regularly (annually) in the segment of sunflower edible oil in Brazil, being two located in MT, one in GO/MG, and one in RS. Table 4 summarizes the main characteristics of the sunflower agri-food chains in each one of these areas as described below.

Mato Grosso (MT) leads the national production and processing of sunflower with two sunflower agri-food chains. Both chains are located in the micro-region of Parecis and centered in Campo Novo do Parecis, where the two processing companies are installed. The largest one has local farmers as major shareholders, while a multinational food corporation owns the other company. Both companies are suitable to process different oilseeds, but only the farmer-led industrial plant focuses its operation on the sunflower edible oil market segment. The combined sunflower processing capacity of the two companies (900 metric tons per day) implies in a potential demanded sunflower area of around 200,000 ha per year. However, the average production area of sunflower in MT in the last five years (2013-2017) was 64,140 ha per year. Regarding the oil destination, the farmer-led company targets food industry consumers, selling non-refined sunflower oil, while the multinational company has a sunflower oil brand focused on final domestic consumers. At the farming level, sunflower production has been concentrated in the micro-region of Parecis. This region has a predominance of large-scale mechanized farms focused on the production of soybean, maize, and cotton. Sunflower is grown in the second season, with the sowing period after the harvest of soybean in Feb/Mar, and the harvest period in Jun/Jul, overlapping the main maize growing season (Jan/Mar-May/Aug). Finally, regarding the inputs segment, sunflower seeds from five companies are available in this region, being traded by local input providers mostly from Campo Novo do Parecis, which also sell other inputs needed to the cultivation of sunflower.

Except for one company (Hiliagro), all other sunflower seeds available in the Brazilian market have been produced abroad – in Argentina (Advanta, Dow, and Syngenta) and Bolivia (Atlântica Sementes).

The second most important sunflower producing and processing region encompasses the states of Goiás and Minas Gerais (GO/MG). The industrial plant of the sunflower agri-food chain is located in Itumbiara (GO) and owned by a national food company. The sunflower processing capacity of 380 metric tons per day results in a potential demanded sunflower area of around 85,000 ha per year, which is more than four times higher than the average producing area of sunflower in this region (19,680 ha per year). The company also produces soybean and maize edible oils, which together with the sunflower oil are mostly sold under its brand to final domestic consumers. The sunflower production is spread over the two states, with a predominance of medium-sized farms and similar sunflower growing season as in MT. However, in GO/MG, the sunflower season overlaps the seasons of maize and sorghum. Regarding the input segment, three brands of sunflower seeds are the main ones available for farmers in this region, being traded by local input providers from several municipalities, which also sell other inputs required for sunflower production.

The state of Rio Grande do Sul (RS) is the third sunflower producing and processing area in Brazil. The industrial plant of the sunflower agri-food chain is located in Giruá, owned by a regional food company, and able to process up to 350 metric tons of sunflower per day. Nevertheless, the company has operated well below this capacity, as indicated by the difference between its potential demanded area of sunflower (77,777 ha) and the average sunflower production area in RS (3,180 ha). The main company's businesses are the production of canola and soybean oils, and the sunflower oil is mostly sold to food industry consumers. At the farming segment, the production of sunflower is dispersed over the northwest region of RS, being typically originated from small and medium-size farms. The sunflower season begins in Aug/Sep and ends in Dec/Jan due to different climatic conditions from MT and GO/MG. Thus, besides overlapping the growing season of maize (Aug – Jan), the cultivation of sunflower also affects the soybean season (Oct/Dec-Mar/May), which is the main crop of the region. At the inputs segment, the processing company operates as sunflower seeds distributor, while local input providers are responsible for selling the other inputs required for the cultivation of sunflower.

Table 4. Characterization of the sunflower agri-food chains in Brazil

Chain segment	Features	MT	GO/MG	RS
Processing	Number of companies	2	1	1
	Location	Campo Novo do Parecis	Itumbiara (GO)	Giruá
	Ownership	Farmers / Multinational food company	National food company	Regional food company
	Processed vegetal oils	Sunflower / sunflower and soybean	Soybean, maize, sunflower	Canola, soybean and sunflower
	Sunflower processing capacity (tons/day)	600 / 300	380	350
	Main sunflower oil destination	Food industry / domestic consumers	Domestic consumers	Food industry
	Potential demanded area of sunflower (ha/year)*	133,332 / 66,666	84,443	77,777
Farming	Average sunflower production area (ha) (2013-2017)	64,140	19,680	3,180
	Geographic distribution of sunflower production	Concentrated in the micro-region of Parecis	Dispersed over two states	Dispersed over the northwest region of RS
	Predominant farm size	Large farms	Medium-size farms	Small and medium-size farms
	Growing season	Feb/Mar – Jun/Jul	Feb/Mar – Jun/Jul	Ago/Sep – Dec/Jan
	Competing crop	Maize	Maize and sorghum	Maize and soybean
Inputs	Sunflower seeds brands available	Advanta, Atlântica Sementes, Dow, Heliagro and Syngenta	Atlântica Sementes, Dow and Syngenta	Advanta and Atlântica Sementes
	Seed vendor	Input providers	Input providers	Processing company

*Estimate based on an average sunflower yield of 1,500 kg/ha and considering 8,000 hours (333.33 days) of processing plant operation. For instance, for the farmer-led company in MT the calculation was done as follow: (600 tons x 333.33 days)/1,500 kg/ha = 133,332 ha/year.

2 Research Objectives

The implementation of innovations in agri-food chains, the growing international demand for food, the call for plant proteins to improve food system sustainability, the technological possibilities for the production of high-quality sunflower protein food ingredients, and the potential for expanding the Brazilian sunflower producing area constitute the background for the objectives of this study.

2.1 General objective

Performing a socio-economic analysis of an agri-food chain focused on a non-established crop in view of the potential implementation of food innovations, using sunflower agri-food chains in Brazil and upcoming sunflower high-quality food protein ingredients as a case study.

2.2 Specific objectives

(1) Analyzing the dynamics of operation of the existing sunflower agri-food chains in Brazil.
(2) Understanding the underlying factors that enabled the recent development of the principal agri-food chain of sunflower in Brazil.
(3) Investigating the potential for expanding the sunflower land use in double cropping systems in the state of Mato Grosso, Brazil.

2 Research Framework

The present study was developed in three sections. Each section addressed a specific research objective and applied either a qualitative methodological approach or a quantitative one. Moreover, the three parts are harmonically connected through the similar research background presented above, and jointly, the sections addressed the general objective of the research. Table 5 and its following description present the sections' titles, the specific research objectives to which each section is related, and the methodological approaches applied.

Table 5. Research framework

Section title	Specific objective addressed	Methodological approach
Using transaction cost economics and the social network approach to explain the dynamics of operation of agri-food chains focused on non-established crops: Multiple case studies from sunflower chains in Brazil.	Analyzing the dynamics of operation of the existing sunflower agri-food chains in Brazil.	Multiple case study embedded design. Semi-structured interviews. Theory-driven interview content analysis (TCE and social network approach).
Agri-food chain establishment as an entrepreneurial process: The case study of a sunflower agri-food chain in Mato Grosso, Brazil.	Understanding the underlying factors that enabled the recent development of the principal agri-food chain of sunflower in Brazil.	Single case study embedded design. Semi-structured interviews. Interview content analysis guided by an analytical framework (Entrepreneurial process).
A bio-economic model-based assessment of sunflower adoption in double-cropping systems in Mato Grosso, Brazil.	Investigating the potential for expanding the sunflower land use in double cropping systems in the state of Mato Grosso, Brazil.	Integrated assessment approach combining an agent-based model (ABM) with a crop growth model (MPMAS/MONICA).

The first section was titled “Using transaction cost economics and the social network approach to explain the dynamics of operation of agri-food chains focused on non-established crops: Multiple case studies from sunflower chains in Brazil”. The aim of this section was to analyze the dynamics of operation of sunflower agri-food chains in Brazil to understand possible ways to supply innovative sunflower food protein from Brazil. Therefore, it addressed the first specific objective of the research.

A qualitative research approach was applied using a multiple case study embedded design (Yin, 2014). Thus, three agri-food chains of sunflower were selected as case studies, comprising the major producing and processing regions of sunflower in Brazil (described in section 1.1.2), namely the states of Mato Grosso (MT), Goiás and Minas Gerais (GO/MG), and Rio Grande do Sul (RS). The primary source of information was semi-structured interviews conducted with 56 agents related to the sunflower chain segments of inputs, farming, and processing, besides researchers, between April and August 2016, which amounted to 1450 minutes of audio recording, and 240 pages of transcripts. The content analysis of the interviews followed a theory-driven approach based on concepts from the transaction cost economics (governance structures and coordination mechanisms) and the social network approach (trust as an informal governance structure) to explain how the economic activities in the sunflower agri-food chains in Brazil are organized and coordinated.

The second section was titled “Agri-food chains establishment as an entrepreneurial process: The case study of a sunflower agri-food chain in Mato Grosso, Brazil”. The aim of this section was to analyze the establishment process of the principal sunflower agri-food chain in Brazil. This objective involved the identification and analysis of the underlying reasons for the rapid development of the major sunflower chain in Brazil, seeking to support the future development of new sunflower chains to meet the expected demand for high-quality sunflower food protein ingredients. Therefore, it addressed the second specific objective of the research.

A single case embedded design research approach was applied (Yin, 2014) using the farmer-driven sunflower agri-food chain in MT as the unit of analysis, and the chain segments of inputs, farming, and processing as the embedded units of analysis. Interviews with 27 sunflower agri-food chain stakeholders conducted between April and July 2016 in five municipalities of MT amounted to 770 minutes of audio recording, and 130 pages of transcripts, providing the information for the development of this study. The content analysis of the interviews was guided by an analytical framework that regarded the establishment of the sunflower agri-food chain in MT as an entrepreneurial process comprised of three stages –

planning, implementation, and growth. Particular attention was given to the identification and analysis of the enabling factors for this agri-food chain endeavor conducted by farmers.

Finally, Section 3 was titled "A bio-economic model-based assessment of sunflower adoption in double-cropping systems in Mato Grosso, Brazil". The aim of this section was to examine the potential for sunflower diffusion into double-cropping systems in MT in view of the possible implementation of food innovations related to sunflower in Brazil. This objective involved: (1) simulating the diffusion path of sunflower in MT with the identification of barriers to its adoption, (2) estimating the potential sunflower production in MT, and (3) evaluating the economic impact of sunflower adoption at the farm-level. Therefore, it addressed the third specific objective of the research.

The methodology comprised an integrated assessment approach, which combined an agent-based model (ABM) with a crop growth model. The ABM was implemented using the software package Mathematical Programming-based Multi-Agent Systems (MPMAS), which uses whole-farm mathematical programming to simulate the decision-making process of farmers (Schreinemachers and Berger, 2011). In the present case, a MPMAS model simulated the decision-making of a farm-agents population with socio-economic and technological characteristics of farms from five agricultural regions of MT. Thus, the model simulated farm-agents decisions regarding land use allocation for soybean, maize, cotton, and sunflower in double-cropping systems. Sunflower was treated as an innovation for farmers. The biological component was represented by a crop growth model for simulating yields for these four crops, and implemented using the process-based model for nitrogen and carbon in agro-ecosystems (MONICA). Crop yields simulated in MONICA take into account different soil types, cultivars, nitrogen fertilization rates, sowing dates, management practices, and climatic conditions (Nendel et al., 2011).

Figure 4 highlights the connection between the sections, which comprise the present research framework. The more stable operation of a farmer-driven sunflower agri-food chain even in the face of hindering factors (e.g., land use competition with well-established crops) identified in Section 1 called for a look in more detail at this farmers' collective endeavor, which was performed in the subsequent section. Section 2, in turn, suggested the existence of a favorable institutional environment for the expansion of sunflower agri-food chains in MT, besides indicating the need of investigating and estimating the potential for the expansion of sunflower diffusion to different agricultural regions of MT taking into consideration the land use competition with other crops grown in the second crop season, which was performed in Section 3. Therefore, the sections as a whole enabled a socio-economic analysis of agri-food chains of sunflower in Brazil, especially at the farming level, with the identification of relevant aspects to be considered before a possible implementation of food innovations related to high-quality plant protein ingredients.

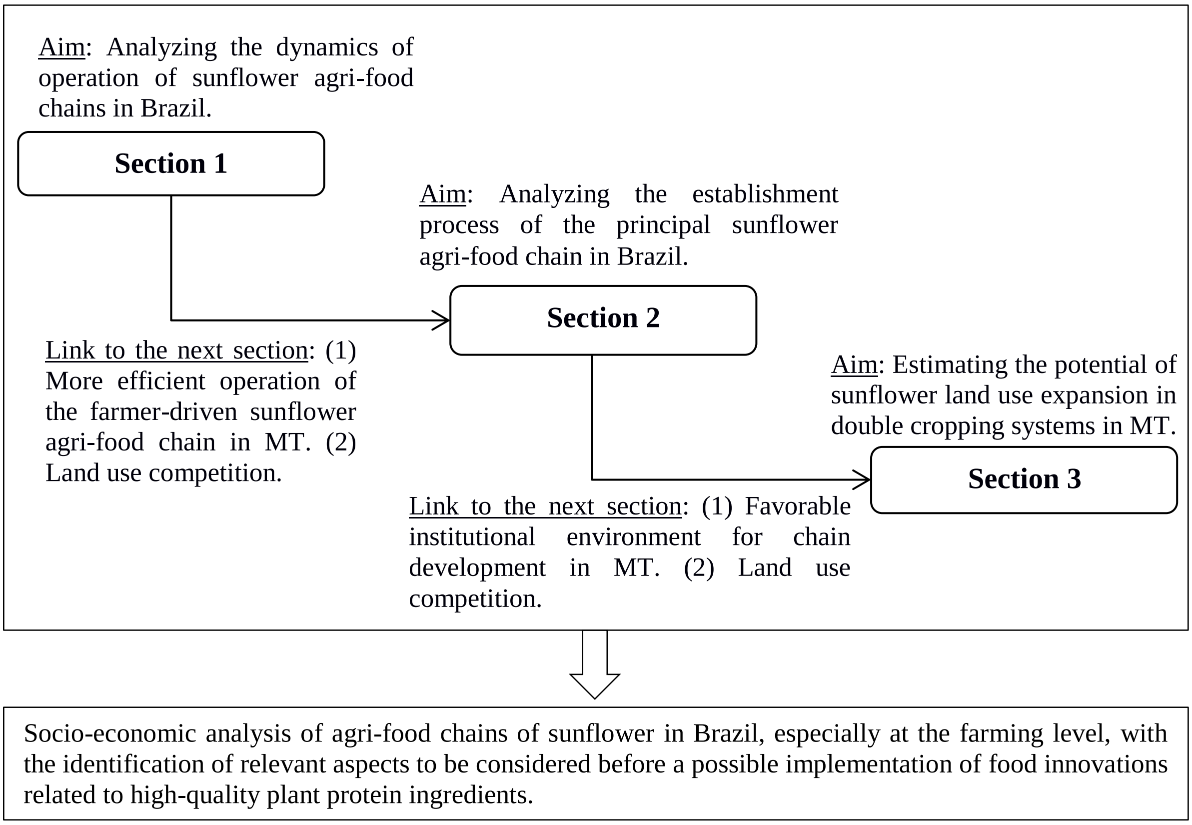


Figure 4. Connection between the sections

3 Contribution for the research on sunflower in Brazil

The potential for sunflower expansion in grain producing areas and the initial establishment of this agri-food chain in MT, Brazil's most important soybean producing region, have recently increased the interest for sunflower research in the field of agricultural sciences in Brazil. Research topics include the description of sunflower production in Brazil (Castro and Leite, 2018), a life-cycle assessment of the soybean-sunflower cropping system in MT (Matsuura et al., 2017), the analysis of sunflower genotypes' performance at different sowing dates in MT (Birck et al., 2017), the identification of nematode-resistant sunflower genotypes adapted to the tropical region of Brazil (Dias et al., 2016), the evaluation of agronomic characteristics of sunflower genotypes cultivated in different regions of the country (Dalchiavon et al., 2016a; Dalchiavon et al., 2016b; Grunvald et al., 2014b), the analysis of technical characteristics of sunflower oils originated from different genotypes (Grunvald et al., 2014a; Grunvald et al., 2013), and the investigation of the relationship between sunflower productivity and chemical properties of soils in MT (Dalchiavon et al., 2015).

Nevertheless, to date, no investigation has addressed the three topics focused on the present study, namely (1) the theory-driven analysis of the dynamics of operation of sunflower agri-food chains in Brazil, (2) the identification and analysis of the underlying reasons for the rapid development of the sunflower agri-food chain in the state of Mato Grosso, and (3) the analysis of the expansion potential of sunflower taking into consideration biological, socio-economic, and technological components of double cropping systems prevailing in the main Brazilian grain-producing region. Therefore, the present study provides additional contributions to the sunflower research development in Brazil by addressing these three research gaps.

SECTION 1 – Using transaction cost economics and the social network approach to explain the dynamics of operation of agri-food chains focused on non-established crops: Multiple case studies from sunflower chains in Brazil[1]

1 Introduction

The replacement of animal protein by plant protein in human nutrition is seen as one of the possible means for achieving more sustainable food systems in some contexts (Aiking, 2014). The driving forces for this change include (1) the growth in population (2-billion over the next four decades) and in income, which is projected to lead to an increase in food demand globally, particularly for proteins (FAO, 2013), (2) the limited capacity of meat supply to meet the expected protein demand, (3) the negative environmental effects associated with livestock production in some places (Bonte-Friedheim, 2008), (4) the concerns on animal welfare (Vainio et al., 2016), and (5) the potentially higher cost of animal protein compared to plant proteins (Frost & Sullivan, 2010). This scenario has induced research and development in the public sector and in the food industry to identify and develop new sources and methods of plant protein production (González-Pérez and Vereijken, 2007; Wu et al., 2014).

Currently, soybean is the major source of plant protein ingredient in food (González-Pérez and Vereijken, 2007). However, the growing use of genetically modified soybeans varieties has led the food industry in developed countries to search for alternative food proteins to soy (Pickardt et al., 2015), as consumers often have a critical attitude towards genetically-modified food. In this regard, sunflower appears as a promising raw material for plant-based proteins (González-Pérez et al., 2002; González-Pérez and Vereijken, 2007; Pickardt et al., 2015; Weisz et al., 2009) Within this context, the research project SunflowerProtein has developed and analyzed novel sunflower processing technologies. The focus is on the production of high quality and functional protein meal and concentrates for human consumption, instead of low-value residues from the conventional de-oiling process, usually destined for animal feed. SunflowerProtein evaluates the cultivation of sunflower and

[1] This section is published as Sousa, L. O. d., Dias Paes Ferreira, M., Vogt, L., Mergenthaler, M., 2018. Contracts, social network and knowledge diffusion in Brazilian sunflower agri-food chains for potential supply of innovative food proteins. *Revista de Economia e Agronegócio - REA.* 16, 8–28.

the possibility of the development of sunflower food protein ingredients in Brazil, given its prominent role in world agricultural supply.

The farming and processing of sunflower in Brazil date from the early 1900s. The planted area, however, has increased only from the late-1990s due to better cultivation and market conditions for sunflower oil (Castro et al., 2010; Dall'Agnol et al., 2005). Nevertheless, the production of sunflower is concentrated, very limited, and oscillating. Three regions in the states of Mato Grosso, Goiás, Minas Gerais and Rio Grande do Sul concentrate more than 97% of the national sunflower production (CONAB, 2018). Moreover, the sunflower cropping area (min. 47,800 ha in 2005 and max. 115,600 ha in 2014) corresponds to less than 1% of the world sunflower production area (USDA, 2018) and less than 1% of the national production area of maize and soybean. Notwithstanding, there is potential for the expansion of sunflower production in Brazil, due to the existence of agro-climatic conditions necessary to enable its cultivation, especially in grain-producing areas (Lazzarotto et al., 2005). Possible negative aspects of this expansion are currently difficult to be projected. Firstly, because it would take place in crop areas, minimizing the risk of deforestation. Secondly, due to the current small size of the sunflower producing area. Thus, even if the sunflower area increases by a factor of 10, it will be still small in comparison with the cultivated area of soybean and maize.

Food innovations like the ones dealt within SunflowerProtein are normally led by the food industry and research institutes (Wu et al., 2014). However, the implementation of such innovations, which rely on agricultural feedstocks specificities, depends on other agri-food chain actors with whom the innovator transacts (Du et al., 2016). This is due to the principles of interdependency, propagation, feedback, and synergy applied to systemic approaches, including agri-food chains (Silva and Souza Filho, 2007). Therefore, implementing a food innovation requires a holistic approach. In other words, it is necessary to understand the relationships among chain actors and the way the transactions take place. This justifies the consideration of formal and informal/relational governance structures for the analysis of agri-food chains (Trienekens, 2011; Trienekens et al., 2014)

Against this background, this section aims to analyze the dynamics of operation of sunflower agri-food chains in Brazil to understand possible ways to supply innovative sunflower food protein from Brazil. The following research question guides this section. How do formal and relational governance structures organize and coordinate the economic activities in agri-food chains of sunflower in Brazil? The analyses performed in this section contribute to the understanding of the operation of agri-food chains focused on new or non-established crops. For policymakers, managers, and practitioners related to the food industry, the findings highlight the need to consider relational governance forms, such as trust, and not only formal contracts to ensure the provision of feedstock and increase the chances of successful introduction of food innovations. Theoretically, it reinforces the complementarity of transaction costs economics and social networks approaches in explaining the functioning of social-economic systems.

2 Theoretical background

The dynamics of operation of a sunflower agri-food chain is related to the way in which the transactions between actors from different chain segments are organized. Therefore, analyzing this dynamics involves the analysis of the governance structures and the coordination mechanisms adopted by the actors to organize the chain's economic activities. Considering that social relations underpin economic transactions, this section adopts two theoretical bases – transaction cost economics (TCE) and the social network approach.

TCE has been widely adopted in the agribusiness research, including in recent food systems analysis (e.g., Watanabe and Zylbersztajn, 2012). Due to this, the following description only highlights the main aspects of TCE (Williamson, 1979; Williamson, 1985). According to this approach, the structures of governance are forms of managing exchanges and include spot markets, hybrid arrangements/contracts, and vertical integration. TCE assumes that transactions are established under human behavioral attributes of bounded rationality and opportunism. Additionally, the appropriate governance structure depends on the characteristics of the transactions (asset specificity, uncertainty, and frequency), which influence the level of transaction costs. The efficient governance structure is the one that minimizes the transaction costs and the risk of transaction failure. Transaction costs are defined as the costs of running the economic system (Arrow, 1969), including costs of finding transaction partners, negotiating, monitoring and enforcing agreements.

Different forms of coordination mechanisms are associated with the governance structures. The coordination moves from the market-managed form (price coordination) at the spot market, to increasing degrees of human-managed forms (vertical coordination). As the degrees of asset specificity, uncertainty, and frequency increase, market-managed coordination via price increases transaction costs to a level at which it does not provide sufficient guarantees for the transactions' establishment. Thus, the actors move away from the spot market in the direction to governance structures able to provide sufficient transaction safeguards (hybrid forms/contracts or vertical integration), minimizing the exchange costs and the risk of transaction failure. Under these structures, vertical (human-managed) coordination takes place.

Although TCE is an important theoretical approach to deal with the operation of agri-food chains, it is not sufficient to explain the coordination of economic activities. The reason is that social relations and not only human/transactions characteristics play a fundamental role in explaining how economic activities are organized. This is directly related to the concept of embeddedness, which refers to the fact that economic activities are embedded in networks of social relations and is shaped by them (Granovetter, 1985). Embeddedness affects the efficiency of formal governance structures (Williamson, 1993) and can be referred to as the highest level of social analysis, formed by informal institutions, customs, traditions, norms, and religion, which are usually taken as given within TCE (Williamson, 2000). Uzzi (1997) was even more specific in this regard by saying that in an embedded logic of exchange, trust acts as the primary governance structure. This section follows Uzzi's perspective to consider social networks, more specifically trust, as a possible structure of governance in agri-food chains of sunflower in Brazil.

Trust is defined as "the firm's [actor's] belief that another company [trading partner] will perform actions that will result in positive outcomes for the firm [actor], as well as not take unexpected actions that would result in negative outcomes for the firm [actor]" (Anderson and Narus, 1990 p. 45). In the context of agri-food chains, trust is considered an informal or a relational governance mechanism, complementing the formal governance mechanisms of TCE (Trienekens et al., 2014; Zhang and Aramyan, 2009). Therefore, TCE and social networks (trust) are complementary approaches to deal with the analysis of the operation of sunflower agri-food chains.

Trust emerges from social relations or networks (Furlong, 1996; Galaskiewicz, 2011) and depends on the duration of the relationship, successful previous experiences between parties and social and economic reputation (Trienekens, 2011). Trust between market actors dampens the incidence of opportunistic behaviors and contractual hazard (Masuku, 2009), decreasing the level of uncertainty surrounding the transaction. Consequently, it reduces the transaction costs and the risk of transaction failure, increasing the willingness of trading partners to invest in specific assets (Barney and Hansen, 1994). Thus, the presence of trust may be seen as an incentive for potential trading partners to engage in exchange, favoring the repetition of future transactions. Since trust lessens the level of transaction costs, it affects the choice for the formal governance structure, in favor of less complex ones in terms of safeguards and monitoring mechanisms (Galaskiewicz, 2011; Trienekens, 2011; Furlong, 1996; Keefer and Knack, 2005). Moreover, trust is regarded as a self-enforcing mechanism for the fulfillment of actors' obligations, facilitating the transaction (Masuku, 2009; Keefer and Knack, 2005). Furthermore, empirical evidence positively relates trust to information exchange, cooperation, and coordination (Galaskiewicz, 2011).

The above considerations on TCE and social network suggest that both formal and relational governance structures might be relevant means for the coordination of the economic activities in sunflower agri-food chains in Brazil. However, only the analysis of the cases can provide understanding on how the adopted governance structures contribute to the dynamics of operation of these chains. This means understanding "the way that institutions [formal and relational governance structures] provide incentives, sanctions, and information to promote particular types of behavior" (Dorward and Omamo, 2009 p. 86)

3 Methodology

This section applied a case study qualitative research approach. The case study is an appropriate method for research dealing with the understanding of complex social-economic phenomena in its real-world context, over which the investigators have no control (Yin, 2014). This is the case of this section's aim at building an understanding of the dynamics of operation of agri-food chains of sunflower in Brazil. Moreover, given the section's focus on analyzing sunflower agri-food chains in different regions in Brazil, a multiple case embedded design was adopted.

In this framework, more than one case (unit of analysis) is analyzed and different embedded units of analysis are considered in each case (Yin, 2014). Three agri-food chains of sunflower were selected as case studies (unit of analysis) based on the availability of the processing companies' representatives to participate in this study. Moreover, the selection of the cases sought to cover all the three regions responsible for the majority of the production and processing of sunflower in Brazil – Mato Grosso (MT) (case 1), Goiás and Minas Gerais (GO/MG) (case 2), and Rio Grande do Sul (RS) (case 3). Besides adding robustness to our findings, the inclusion of all three regions in the study enabled the identification of similarities and specificities of the cases. The embedded units of analysis considered in each case were the chain segments of input, farming, and processing (Figure 5).

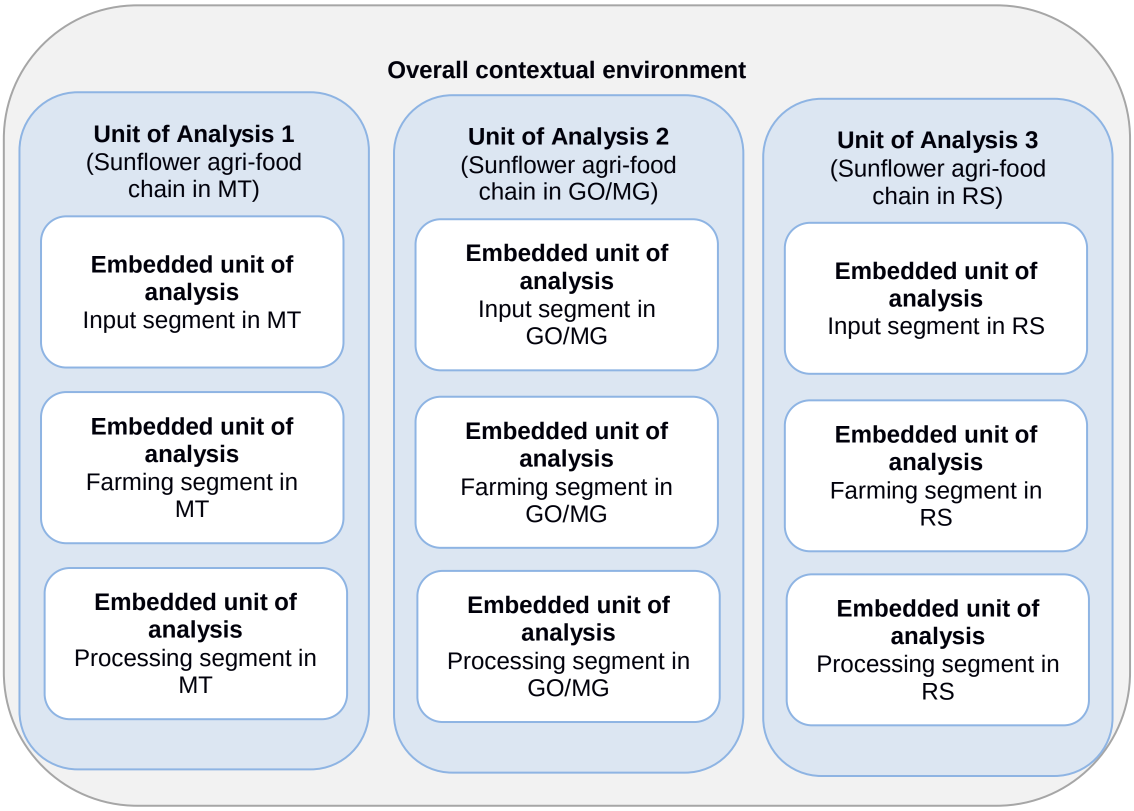


Figure 5. Multiple case study embedded design adopted in this section

Fieldwork for data collection in the four states was conducted between April and August 2016. Semi-structured interviews held in Portuguese with 56 sunflower-related actors (Table 6) are the main source of information utilized in this section. Table 6 includes four actors from research institutions. Although they are not part of an embedded unit of analysis, their participation adds to the comprehension of the environment in which the agri-food chains of sunflower operate. The open-ended questions focused on the emergence process of these agri-food chains, seeking to understand what motivates the participation of actors from the three segments in the business of sunflower. This enabled the analysis of the dynamics of agri-food chain operation performed in this section. The duration of the interviews varied across the actors and the regions, and the average lengths are shown in Table 6. The recorded interviews amounted to around 1450 minutes.

Table 6. Number of interviewees (A) and average length of the interviews in minutes (B)

Chain segment	Case 1		Case 2		Case 3		National	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**
Processing	1	100	3	50	1	70		
Farming	14	25	11	27	9	17		
Input	7	44	5	39	4	23		
Research	2	26					2	39

Additionally, direct observation was another source of evidence to understand the dynamics of operation of the agri-food chains of sunflower in Brazil. Direct observation contributes to the comprehension of the social or environmental real-world conditions of the phenomena being studied, providing to the researcher in-depth involvement with the research problem (Yin, 2014). Direct observation was performed during site visits to farm supply retail stores, farms, and processing companies, besides in agricultural fairs (in Mato Grosso and Goiás) and farmers' activities (e.g., a farmers' field day in Mato Grosso). Furthermore, valuable occasions for direct observation resulted from the opportunity to closely accompany technical teams from the processing and input segments in their work of farmers' assistance.

The transcripts of the recorded interviews amounted to 240 pages, and the qualitative data analysis software MAXQDA (version 11 version 11, VERBI Software GmbH, Berlin, Germany) assisted the process of interview transcripts analysis, enabling the development of a coding system to tag the interviews quotes. MAXQDA facilitated the cross-case analysis, which was the analytical approach adopted in this section to identify and analyze common patterns in the operation of agri-food chains of sunflower in Brazil. The similarities in the dynamics of operation of the three sunflower agri-food chains would lead a within-case analysis to repetitive writings. Nevertheless, the main regional particularities of each case study were treated in the analysis.

4 Analysis

4.1 The operational environment

The three sunflower agri-food chains analyzed in this study operate in an environment of high transaction costs. This fact is related to the high level of uncertainty associated with the low number of sunflower buyers and the unstable number of growers. When a farmer grows sunflower, he or she has very few buyers (in some cases only one) available in the region. This inhibits the entry of farmers in the sunflower business, as for competing crops such as maize they have several traders willing to buy it, which makes sunflower less competitive. Furthermore, the transportation cost of sunflower is usually more expensive[2] than for other crops (soybean and maize), limiting the possibility of profitably selling sunflower to buyers from other regions. These facts make the farmer highly dependent on the (single) buyer.

However, asset specificity for farmers is relatively low. On the one side, the farmer, who already grows soybean and maize, can use the existing farm infrastructure, machinery, and personnel to grow sunflower as an additional field crop. The direct investment (cost) to enter in the sunflower business refers basically to an adaptation in the combine header of maize (mainly) or soybean. This adaptation has a low cost and can be done in the farm. The knowledge on sunflower cropping can also be considered a specific asset, however as discussed further, this investment is assumed mainly by the processing company and the input providers. Consequently, there are low entry/exit costs for farmers, making easier for them the decision to leave the crop in the face of technical or commercial dissatisfactions.

On the side of the processing company, uncertainty is increased due to a higher degree of asset specificity as compared to farmers. Given that the companies in the three cases operate with multi-seed plants, the assets specificity is more related to intangible assets. Thus, the main losses in case of closure of the sunflower business would not be related to the physical infrastructure, which can continue to be used with other oilseeds. Rather, the losses would be related to the resources applied to establish a competitive positioning in the market of sunflower oil, which is a niche market within the edible vegetable oil sector in Brazil, led by soybean oil.

The unstable number of growers leads to high transaction costs on the side of the processing company. Difficulties to stabilize the supply of sunflower for the processors are related to several reasons, such as (1) the fact that farmers have other well-established crops to grow in the same crop season results in land use competition, especially with maize that ensures higher levels of stable liquidity due to higher number of buyers, (2) the fact that sunflower usually represents a small share of farmers' income, which is mainly derived from soybean and maize, (3) low farmers' exit costs, (4) low level of sunflower cropping knowledge observed among farmers, (5) a disease called "white mold", caused by the plant pathogenic fungus sclerotinia sclerotiorum, which besides affecting sunflower can generate

[2] This is because the sunflower seed is bigger but lighter than soybean and maize.

losses for the subsequent soybean cultivation, mainly in areas of Goiás and Minas Gerais (GO/MG), and (6) low level of research and technology for sunflower in comparison with consolidated crops (soybean and maize), which can be seen by: the low number of researchers working on sunflower topics in Brazil, the low number of agrochemicals registered in the Ministry of Agriculture for the crop of sunflower, and the fact that most of the sunflower seeds available in Brazil are imported from Argentina or Bolivia and are not well-adapted to the Brazilian conditions.

This scenario generates interdependencies between farmers and the processor with different time horizons. In the short term (within a crop season), the farmer is highly dependent on the processing company after deciding to grow sunflower, given the very limited number of sunflower buyers available. However, in the long term, the processing company depends more on the farmers to guarantee the supply of sunflower. Consequently, the power relations between these agents are balanced. In other words, the potentially high short-term market power of the buyer is reduced due to its long-term dependence to its suppliers.

4.2 Dynamics of chain operation

The operational environment previously described has a direct influence on the dynamics of operation of sunflower agri-food chains in Brazil (Figure 6). This dynamics seeks to provide the incentives and safeguards for the engagement of actors in the sunflower agri-food chain. Within this dynamics, the organization of the economic activities involves contracts, social network, and knowledge diffusion under the coordination of the processing company.

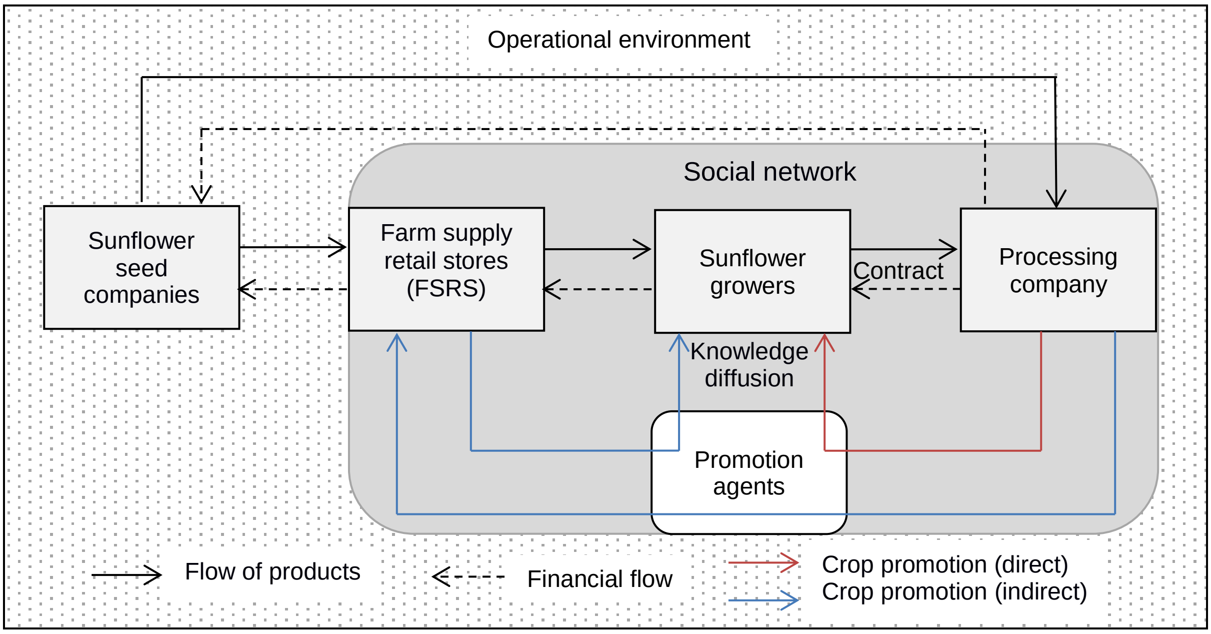


Figure 6. Dynamics of operation of agri-food chains of sunflower oil in Brazil[3]

"Crop promotion" is the key driver of this dynamics. Crop promotion puts together contractual relationship, social network, and knowledge diffusion with the goal of encouraging and assisting farmers in the growing of sunflower to be supplied to the processing company. The crop promotion is executed by promotion agents – technical teams of agronomists or agricultural technicians employed by the sunflower processor and/or by farm supply retail stores (FSRS). The crop promotion execution assumes mainly two approaches. In the direct approach, agents from a processing company are responsible for reaching and assisting farmers. In the indirect approach, agents from FSRS actively participate in the crop promotion. In this case, the FSRS assumes the responsibility for promoting sunflower among farmers in its area of commercial coverage, linking them to the processing company. This represents a typical win-win relationship. The processing company benefits from the influence that a FSRS has over a large number of farmers, with whom it maintains close commercial and personal relationships. On the other hand, the FSRS benefits from the selling of inputs necessary for sunflower growing.

Contracts between the farmer and the processing company provide the formal transaction safeguards. The operational environment of the sunflower chains in Brazil requires vertical coordination mechanisms to guarantee their operation. In this regard, contracts are the formal governance structure adopted in the three cases. They specify in

[3] The lines connecting the sunflower seed segment to the processing company represents an inter-segment relation found in the case 3 (RS), where the processing company is also the sunflower seed distributor.

advance the conditions related to amount, price, payment, and delivery of sunflower seeds, besides the penalties for noncompliance. The use of contracts reduces the uncertainties for farmers and the processing company. In the crop promotion approach, the contracts are offered to the farmer by the promotion agent.

The social network component is another essential factor for the sunflower chains operation in Brazil. Because sunflower is a non-established crop, its adoption is considerably influenced by personal relationships. This influence can come from a sunflower grower perceived as reliable and from a promotion agent, who is the person responsible for introducing the crop to farmers, showing technical, economic, and commercial aspects of the sunflower business. The participation of farmers in the chain linked to personal relationships decreases the risk of transaction failure since the involvement of personal ties and trust diminishes the incentives for opportunistic actions. Farmers believe that the processing company will stick to the prices agreed in the formal contracts. At the same time, the processing company believes that farmers will indeed deliver their sunflower seeds and will make all necessary efforts to ensure that the agreed quantities will be delivered (so that the processing company can fulfill the contracts with its customers). With these examples, it becomes clear that the above-given definition of "trust" plays a crucial role in the operation of the sunflower chain. Additionally, the reputation of the processing company is another aspect of the social network component. The restricted market structure reinforces the importance that farmers give to the good reputation of the buyer. Even previous negative experience of other farmers with other sunflower buyers (already out of the market) limits the interest of some farmers to enter or remain as suppliers in sunflower chains. This is not the case for well-established crops since farmers are more likely to continue in the market even after losses caused by trading partners' opportunistic behavior. Thus, the relevance of the social network component in terms of reliable personal relationships and good reputation suggests that trust constitutes the basic component of a relational governance structure in sunflower agri-food chains in Brazil. Trust is a necessary incentive for the transaction establishment in addition to formal contracts.

The knowledge diffusion is also a key component in the operation of the sunflower agri-food chains in Brazil. Although the provision of technical assistance is not exclusive to sunflower chains, it plays a major role in agri-food chains focused on new or non-established crops for which the cropping knowledge among farmers is still limited. In this context, the technical assistance (knowledge diffusion) is a determinant for the entrance and continuity of farmers in the agri-food chain. Moreover, different from well-established crops, as soybean and maize, the knowledge on sunflower cropping is limited to a small number of actors and organizations in Brazil. For these reasons, the provision of technical assistance is part of the crop promotion approach. Besides being the mean for knowledge diffusion, the presence of the promotion agent in the farm for technical assistance during different periods within the sunflower season diminishes the incentives for moral hazard related to farmers' opportunistic behavior. Furthermore, it enables the processing company to adopt a flexible contractual posture. For instance, in case of non-provision of the agreed amount of sunflower seeds by a farmer, the processing company knows if this was related to some uncontrolled source (e.g., unsatisfactory outcomes due to seed's problems, diseases, drought, etc.) or to opportunistic or negligent behaviors. Thus, given the small size and the instability in the supply of sunflower mentioned earlier, the processing companies in the three cases have not applied contractual penalties when the noncompliance causes are not under control of the sunflower grower. This kind of behavior enhances the social network component in the dynamics of chain operation, as farmers see the company as a reasonable trustful partner.

4.3 Regional specificities

The level of crop promotion effort applied by the processing company and the role of farm supply retail stores (FSRS) in the dynamics of chain operation differs regionally (Table 7). The differences are mainly related to ownership of the processing companies, farmers' business structures, geographical distribution of sunflower production, and seasonality of crops, as described below for each one of the cases.

Table 7. Crop promotion effort and the role of FSRS at regional level

	Case 1	**Case 2**	**Case 3**
Crop promotion effort: direct approach	Low	High	High
Crop promotion effort: indirect approach	Medium	High	Low
Role of FSRS in the agri-food chain	Cooperative	Strategic	Basic

The crop promotion effort applied in case 1 can be classified as low regarding the direct approach, and medium regarding the indirect approach. This agri-food chain emerged from an entrepreneurial initiative of farmers, who participate in the ownership of the processing company and provide part of its feedstock. Consequently, the need of searching for suppliers is reduced. Moreover, the concentration of sunflower growers in one municipality facilitates the interaction among them and the process of knowledge diffusion. Furthermore, the predominance of large-scale mechanized farms implies self-capacity for access to technical assistance.

This combination of factors results in lower transaction costs for this processing company in comparison to the ones in cases 2 and 3. The crop promotion executed by the processing company, by means of the farmers in leadership positions, refers to the organization of activities for the exchange of experiences and information among farmers. Besides that, the company has a technical department in which one agricultural technician works with the goal of identifying more suitable techniques for the local growing of sunflower. Agents from the input sector coordinate the indirect approach of crop promotion. The focus is on promoting sunflower among farmers outside of the main sunflower-producing municipality, linking them to the processing company. The FSRS play a cooperative role. In general, the FSRS do not actively search for sunflower growers. Instead, they provide support for their clients who decide to grow sunflower. Moreover, the FSRS organize events related to the crop of sunflower generally in partnership with the processing company (e.g., farmers' field days).

In case 2, both approaches of crop promotion are highly utilized and focused on finding and supporting sunflower growers. This is related to the non-participation of farmers in the ownership of the company, which increases the instability of suppliers; the predominance of medium-sized farms that depends more on technical assistance; and the geographical dispersion of sunflower production over two states, which makes the direct approach insufficient. The company has a sunflower business unit in which two agronomists are responsible to coordinate the activities of sunflower crop promotion in partnership with farm supply retail stores. The FSRS play a strategic role in the operation of this agri-food chain. Once the adoption of sunflower in this region is highly influenced by farmers' relations with promotion agents from FSRS, the provision of sunflower for the processing company would be considerably lower without the participation of FSRS.

In case 3, we found a high level of crop promotion by means of direct approach and a low one in terms of indirect approach. The need for crop promotion in this region is explained by the non-participation of farmers in the ownership of the processing company; the predominance of small and medium-sized farms; and, mainly, by the overlapping of sunflower and soybean seasons. This competition with soybean does not occur in the other two chains, where sunflower overlaps the maize and sorghum seasons. Since farmers normally use the whole arable land to grow soybean, the interest for sunflower in this region is considerably smaller. Besides processing sunflower, the company also operates as a sunflower seed distributor. Thus, the crop promotion team employed by the company searches and supports sunflower growers, but also develops field trials with seeds. The goal is to identify more suitable cultivars for the region, especially concerning a shorter production cycle. This would minimize the overlapping period with the soybean season, contributing to a better fit of sunflower within the local agricultural production system. The small number of sunflower growers related to this chain makes the direct approach of crop promotion the main one. Nevertheless, a few partnerships with FSRS exist, as the company seeks to expand the production area of sunflower. Moreover, the indirect approach of crop promotion is a way to reduce the transaction costs for the company with the assistance of small sunflower suppliers. Even so, the FSRS currently play the basic role of providing inputs, except sunflower seed, to sunflower growers.

4.4 Challenges for a long-term sustainable operation

The sunflower cases in Brazil suggest that the long-term efficient operation of agri-food chains focused on new or non-established crops is challenging. Limited market structure, land use competition with well-established crops (e.g., maize and soybean), and technological limitations (e.g., regarding plant breeding and control of pests and diseases) represent some of the barriers for the long-term economic sustainability of sunflower agri-food chains in Brazil. Consequently, the existing formal and relational governance structures associated with knowledge diffusion have not been sufficient to increase and stabilize the supply of sunflower in Brazil.

The instability in the sunflower supply despite the applied governance structures suggests further considerations. First, it points to the existence of a dynamic interplay of different governance structures that take place both simultaneously and over a certain period, influencing production decisions and marketing of crops. The governance arrangement based on contracts, social network, and knowledge diffusion is more effective in the short-term, or within the crop season. This is especially true for the cases in which farmers do not participate in the control of the processing company. Although in the short-term (within a crop season) this governance arrangement is a necessary incentive for the farmer's decision to adopt sunflower, as well as a self-enforcing mechanism for fulfillment of the transaction, it has not been sufficient for ensuring the repetition of the transaction every year (as occurs with soybean and maize), due to the limitations of a non-established crop. Nevertheless, the governance arrangement adopted is decisive for the re-entrance of former suppliers in the sunflower agri-food chain, once the market conditions seem attractive to them, which can be considered a long-term benefit of this arrangement.

5 Discussion

Our analysis confirms the complementarity between transaction costs economics (TCE) (formal governance structures) and the social network approach (relational governance structure) concerning sunflower agri-food chains in Brazil. This is consistent with other studies based on different agri-food chains from different countries (Chagomoka et al., 2014; Fritz and Fischer, 2007; Gërdoçi et al., 2016a; Gërdoçi et al., 2016b; Martino, 2010; Trienekens, 2011; Zander and Beske, 2014; Zhang and Aramyan, 2009). An additional contribution of this section is the identification of the prominent role of knowledge diffusion and the elaboration of an integrated approach to explain the agri-food chain operation based on three key components – contracts, social network and knowledge diffusion. This approach appears especially appropriate for agri-food chains focused on new or non-established crops, as also observed in the case of the agricultural chain of castor bean in Brazil (Watanabe and Zylbersztajn, 2012). Furthermore, the analysis showed that the combinations of low exit cost for farmers and land use competition contribute to balance the supplier/buyer power relations due to different time horizons interdependencies. These interdependencies associated with the social network component dampen the risk of transaction failure.

The feedstock instability suggests a lack of supply chain management (SCM) in the operation of the agri-food chains of sunflower in Brazil. This is a fact also identified in other agri-food chains' studies (Anastasiadis and Poole, 2015; Bourlakis et al., 2012). Furthermore, this evidences that, despite the presence of significant level collaboration and cooperation among chain actors (especially in the case in which farmers own the processing company), the establishment of well-managed agri-food supply chains is a complex endeavor that demands further business development investments.

One of the case studies points out that a close intertwining of farmers and processing company increases the stability and efficiency of an agri-food chain operation. Under this arrangement, the risk of feedstock shortage as well as transaction costs (e.g., associated with the searching and supporting of suppliers) are lower. This farmers' entrepreneurial initiative suggests the existence of enabling conditions (e.g., farming and managerial capacity, access to resources, collaboration, and institutional environment) necessary for successful agri-food chains development (Donovan et al., 2015; Kahan, 2012; Lie et al., 2012).

Vertical integration would appear as a strategy to circumvent the lack of supply chain management. However, recent studies have shown that vertical integration depends on several aspects such market power, in-house feedstock costs, externally feedstock costs, trust, and capital constraint (Zilberman et al., 2017; Du et al., 2016). From a processing company perspective, upstream integration appears to be a challenging task for several reasons. First, the main competition is for land and not for the product itself. Therefore, processing companies are not able to exert market power over farmers by producing some amount of sunflower in-house. Second, the main agricultural activities in the studied regions are soybean and maize. Thus, the purchase of feedstock such as sunflower from external sources appears to be cost-effective over in-house production. As farmers normally cultivate two different crops in the same area per year, the land cost for sunflower production is smaller due to economy of scope. Also, sunflower production on a large-scale basis would present high supervision costs, disabling vertical integration. Third, in a trusted environment, as sunflower production in Brazil appears to take place, the uncertainty regarding externally feedstock supply is addressed. This makes vertical integration less necessary. Fourth, if processing companies face capital constraint, they should invest in processing machinery instead of buying or renting agricultural land. The downstream vertical integration found in case 1 is somehow puzzling. Although the farmers own the processing company, both segments take decision separately. Besides, as the demand for feedstock increase, the processing company should rely on more external feedstock supply to deal with aspects highlighted above.

6 Conclusion

The economic transactions in the Brazilian sunflower agri-food chains are ruled by formal and relational governance structures and made possible through knowledge diffusion. Contracts, a social network based on trust, and knowledge diffusion are necessary conditions for the operation of the agri-food chains of sunflower in Brazil. Nevertheless, this governance arrangement has not been sufficient to guarantee a sustainable long-term operation of these chains, jeopardizing their expansion. Therefore, contracts, social networks, and knowledge diffusion provide the initial or short-term stimulus to the agents of the farming segment supplying sunflower to a processing company. However, the reduction of the long-term operational instability is subject to better market, technological, and supply chain management conditions, which should be addressed by innovators from the food industry possibly interested in implementing high-quality sunflower protein ingredients in Brazil.

Regional characteristics play an important role in the chains' dynamics. The agri-food chain wherein farmers with managerial capabilities participate in the ownership of the processing company presents a more consistent trustful relational environment, a stronger stimulus to knowledge diffusion, and less instability and risk of feedstock shortage as well as transaction costs. The higher the geographical dispersion of raw material suppliers and the processing company's scale of production, the greater the transaction costs and the strategic role of local farm supply retail stores for the chain operation. Finally, land use competition with the principal crop (soybean or maize) has a significant negative impact on the chain operation, resulting in smaller production area and higher transaction costs.

The more stable operation of the farmer-led sunflower agri-food chain in MT even in the face of hindering factors (e.g., land use competition with well-established crops) calls for a look in more detail at this farmers' collective endeavor, which might contribute to the future development of other sunflower agri-food chains in Brazil. This is the topic of the next section.

SECTION 2 – Agri-food chains establishment as an entrepreneurial process: The case study of a sunflower agri-food chain in Mato Grosso, Brazil[4]

1 Introduction

The current scenario of the worldwide increase in food demand calls for substitution of animal protein for plant protein for human consumption to enhance the sustainability of food and agricultural production (Aiking, 2014). Overall, animal protein is regarded as a less sustainable protein source, since it is more natural-resource-intensive in comparison with plant protein (Sabaté and Soret, 2014), it is more costly for the food industry (Frost & Sullivan, 2010), and it is increasingly subjected to consumers' ethical concerns on animal welfare (Vainio et al., 2016). Consequently, the food research started to focus on the development of new sources and methods of plant protein production (González-Pérez and Vereijken, 2007; Wu et al., 2014). Soybean is currently the major source of plant protein food, with the widest range of applications (Frost & Sullivan, 2010; González-Pérez and Vereijken, 2007). Despite the lack of scientific consensus (Zilberman et al., 2018), there are increasing concerns about the use of genetically-modified soybeans, which have led many food manufacturers in Europe searching for alternative plant protein ingredients (Pickardt et al., 2015), among which sunflower appears as a promising raw material (González-Pérez and Vereijken, 2007; González-Pérez et al., 2002; Pickardt et al., 2015; Weisz et al., 2009).

Against this background, the research project "Sustainable cultivation and novel processing of sunflower seeds for simultaneous production of sunflower oil, solid fuel and protein-rich food ingredients" (SunflowerProtein) has proposed a concept of sunflower processing that enables the recovery of vegetable oil, high-value food proteins, and solid fuels. This is achieved through a novel and sustainable technology for a complete utilization of all fractions of sunflower seeds, which allows the production of sunflower protein meals and concentrates suitable for human consumption instead of the low-value residues from conventional de-oiling, normally sold as livestock feed. Moreover, SunflowerProtein aims at ensuring and enhancing sustainability in agriculture, by evaluating the cultivation of

[4] This section is published as Sousa, L. O. d., Dias Paes Ferreira, M., Mergenthaler, M., 2018. Agri-food chain establishment as a means to increase sustainability in food systems: Lessons from sunflower in Brazil. *Sustainability.* 10, 2215.

sunflower as an additional crop on existing agricultural areas in Brazil, seeking to enhance crop diversification, responsible land use, and farmers' income.

The sunflower sector is a small, but promising, agricultural sector in Brazil (Castro and Leite, 2018). The sunflower production and processing is concentrated in three areas in the states of Mato Grosso (MT), Goiás/Minas Gerais (GO/MG), and Rio Grande do Sul (RS). Moreover, the planted area has never been greater than 150,000 ha, which represents less than 1% of soybean and maize planted areas (CONAB, 2018). Nevertheless, the country has potential for expanding the sunflower sector and can provide a supply side response to an expected growing demand for sunflower protein. The main reason for this is the suitability of sunflower to be grown after the harvest of soybean in the same growing season. The cultivated area of soybean in MT (9.3 million ha in 2016/2017) (CONAB, 2018) indicates the enormous potential for an extension of the sunflower cultivation in soybean producing regions, as sunflower is cultivated in succession to soybean within double-crop systems. Furthermore, the introduction of sunflower in double cropping systems has been regarded as a way of improving the sustainability of the agricultural production system in Brazil, especially in MT, which leads the national production of soybean and sunflower. Several aspects support the association of sunflower with a more sustainable agricultural system in MT (Castro and Leite, 2018; Dias et al., 2016; Matsuura et al., 2017). Sunflower farming takes place in existing grain-producing areas between February and July, when the weather conditions are less favorable to the infection with *Sclerotinia sclerotiorum*, a harmful pathogen common to sunflower and soybean. Moreover, sunflower contributes to the pest management of certain nematodes infestation, which is a severe problem in grain-producing areas in Brazil. Furthermore, sunflower farming provides a viable additional income source for farmers, different from other non-commercial alternative cover crops available for farmers, such as millet, *Crotalaria spectabilis*, and *C. ochroleuca*. Finally, sunflower cultivation in succession to soybean reduces environmental impacts due to crop diversification, land use intensification, and the more efficient usage of production factors available on the farm, such as land, agricultural inputs, machinery infrastructure, and labor force.

Currently, only four agri-food chains produce and process sunflower into edible oil at the large scale in Brazil, among which a farmer-driven sunflower chain in Mato Grosso (MT) stands out in terms of operational stability, being the most recent, but the largest one, and the only one focused on the sunflower business. However, the favorable agro-climatic conditions for sunflower cultivation in the country (Castro and Leite, 2018), the association of sunflower cultivation with a more sustainable agricultural system in Brazil (Castro and Leite, 2018;

Matsuura et al., 2017; Dias et al., 2016), and the possible participation of Brazil in the upcoming market of high-quality sunflower protein ingredients (presented in the general introduction) can drive the sunflower sector expansion in Brazil. This expansion might require the establishment of new sunflower agri-food chains, especially in MT, which has led the Brazilian production of sunflower for more than a decade. Notwithstanding, the favorable agro-climatic conditions and the benefits of sunflower cultivation could not be sufficient to ensure well-developed sunflower chains in MT. Hence the importance of understanding the enabling factors for the establishment of Brazil's principal sunflower agri-food chain, seeking to set up successful strategies to meet the expected increase in sunflower demand to the market segment of plant protein ingredients.

Therefore, this section aimed at analyzing the establishment process of the leading sunflower agri-food chain in Brazil, based on the following research question. How can the underlying reasons for the sustainable farmer-driven sunflower agri-food chain initiative in Mato Grosso support the development of new sunflower chains in Brazil? Concentrating on this question, a case embedded design research approach was applied, involving stakeholders from the input, farming, and processing segments. Moreover, the analysis was guided by an analytical framework that regards the establishment of the sunflower agri-food chain in MT as an entrepreneurial process comprised of three stages – planning, implementation, and growth – with focus on the identification of the enabling factors for the process.

This section provides relevant information about the role of MT as a future feedstock supplier for high-quality sunflower protein ingredients in the study region, besides indicating the potential for sunflower expansion to other areas. Moreover, it sheds light on a still under-researched issue in the agri-food chain research. Although several subjects related to agri-food chains have been widely explored in the literature, the effective establishment of agri-food chains is a critical and seemingly under-researched issue (Donovan et al., 2015), which suggests the need for further understanding on the process of agri-food chain establishment. In other words, analyzing how an agri-food chain is formed, moving from the "non-established chain" to the "established chain" status. The existing research on this issue has mainly focused on the identification of hindering factors, challenges faced, and possible upgrading strategies related to agricultural chains established among smallholder farmers (e.g., the castor bean biodiesel chain in Minas Gerais, Brazil (Watanabe and Zylbersztajn, 2012); the palm biodiesel chain in the state of Pará, Brazil (César and Batalha, 2013); and the dairy goat agri-food chain in Tanzania (Lie et al., 2012). Thus, the analysis performed in this section contributes to shed light on this issue, with a different approach, since we focused on the identification of factors that have enabled a successful process of an agri-food chain establishment among large-scale farmers, which is relevant in the context of the agricultural production system in Brazil, particularly in MT.

To date, no investigation has been conducted to understand the underlying reasons for the rapid development of sunflower sector in MT. Thus, this section provides an additional contribution for the sunflower research development in Brazil by addressing this issue, which can provide relevant information to public and private stakeholders aiming to foster sunflower production and processing to meet an expected increasing demand for high-quality sunflower protein.

2 Analytical framework

This study regards the establishment of an agri-food chain as a process of collaboration among individuals and organizations to establish a new business based on a specific crop or livestock at different chain segments (input, farming, and processing) within a particular region and under a certain governance structure. Although this phenomenon could be analyzed under different theoretical approaches (e.g., supply chain management, and Marshall industrial district approach), the entrepreneurial approach seems particularly suitable for analyzing the establishment of the sunflower agri-food chain, once the research field of entrepreneurship is fundamentally concerned with understanding how economic activities come into existence (Venkataraman, 1997). Moreover, the definition of entrepreneurship as a process that includes the discovery, enactment, evaluation, and exploitation of opportunities to create future goods and services (Guterman, 2015) also points to the suitability of entrepreneurship to support the analysis of the sunflower chain establishment performed in this study. Thus, inspired by the model of the entrepreneurial process (Bygrave, 2010), we propose a framework to analyze the sunflower agri-food chain establishment as a process comprising three stages—planning, implementation, and growth, which are influenced by enabling factors (Figure 7).

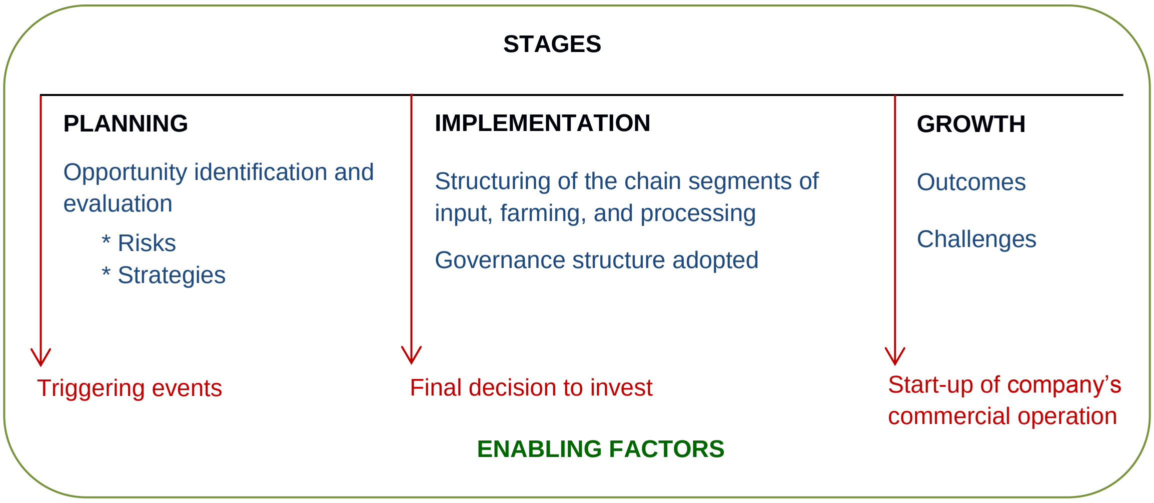


Figure 7. Analytical framework of the process of sunflower agri-food chain establishment

The planning stage begins with triggering events that lead to the initiation of the agri-food chain establishment process. In this stage, the focus is put on analyzing how the opportunity related to sunflower was identified and evaluated, which includes the identification of risks and risk-minimizing strategies, if any, applied by the organizing group. The identification and evaluation of business opportunities are a key part of entrepreneurship (Ardichvili et al., 2003). The implementation stage starts after the final decision to invest in the agri-food chain establishment. At this stage, the focus is set on identifying how the chain segments were structured and which governance forms were adopted to coordinate the economic activities of the nascent chain. In the context of agri-food chains, contractual and relational governance structures can be used to rule the economic transactions (Trienekens, 2011; Zhang and Aramyan, 2009). The start-up of company's commercial operation, in turn, marks the beginning of the growth stage. In this stage, the focus is set on analyzing the main outcomes and challenges over the agri-food chain growth trajectory.

Given that this study aims at understanding the underlying reasons for the success of a farmer-driven agri-food chain initiative, this implies necessarily the identification of factors that enabled the accomplishment of each process stage. Enabling factors are related to the individuals involved in the process and to the local and macro environment in which the endeavor takes place, including personal, sociological, environmental, financial, economic, legal, political, technological, and organizational factors (Carayannis et al., 2015; Bygrave, 2010). Concerning the personal factors, the entrepreneurial skills of the actors involved in the chain establishment process are an important part of the enabling factors. Entrepreneurial skills include: initiative, an opportunity-seeking behavior, the ability to detect, develop, and implement opportunities, a planning capacity, a forward-looking vision, creativity, the willingness for taking calculated risks, the focus on the achievement of goals, perseverance, determination, and ability to react to frustration, a network of contacts, leadership, a wealth and value-seeking behavior, business field experience, market orientation, and management ability (Nassif et al., 2010). Thus, the present framework seeks to guide the analytical description of the sunflower agri-food chain establishment process, focusing on the identification and analysis of its enabling factors.

3 Methodology

This chapter applies a case study approach, which is a suitable research method for investigating underlying processes that might explain complex social-economic phenomena out of researchers' control in its real-world context (Yin, 2014), such as the establishment process of a sunflower agri-food chain. For this reason, the case study is a useful methodological tool for the agribusiness research (Sterns et al., 1998), being largely adopted by researchers of this field.

More specifically, we adopted a case embedded design (Figure 8), in which different embedded units of analysis are considered within an unit of analysis that is, in turn, surrounded by a contextual environment (Yin, 2014). The unit of analysis is the main sunflower agri-food chain in Brazil, located in the state of Mato Grosso (MT). The embedded units of analysis refer to the chain segments of inputs, farming, and processing.

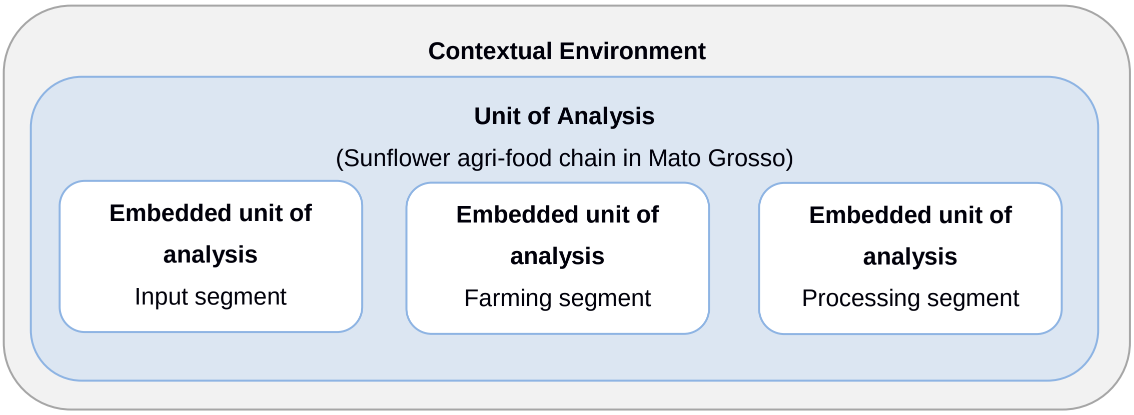


Figure 8. Case embedded design adopted in this study

Fieldwork for gathering information in the sunflower-producing area in MT was carried out between April and July 2016. The fieldwork was carried out in five municipalities

– Campo Novo do Parecis, Brasnorte, Sapezal, Campos de Júlio, and Sorriso. The main area, however, was Campo Novo do Parecis, where the processing company is located and where most of the individuals involved in the agri-food chain establishment reside.

The identification of research participants/respondents started in 2014 and 2015. In this period, two meetings were held in Campo Novo do Parecis to present the research project SunflowerProtein to stakeholders of the existing sunflower agri-food chain, which is the unit of analysis of the present section. During the fieldwork the interviewees from the different embedded units of the analysis were selected. The criterion used for selecting the informants was the participation in the process of sunflower chain establishment. In this regard, the starting point was the contact with the processing company representatives, who indicated farmers and agents from the input segment that were part of the sunflower chain initiative. Additionally, the fieldwork period in the study region and the informal relationships established with local agricultural agents also contributed to the identification of 27 sunflower agri-food chain stakeholders from the input, farming, and processing segments, besides representatives from the research sector willing to participate in the study (Table 8). The apparent high number of interviews with input suppliers in comparison with interviewees from the farming and processing segments is due to higher diversity verified in that segment especially in terms of seed brands. Typically, each input provider is a dealer of only one of the five sunflower seed companies with commercial representation in the region. Therefore, we sought to capture the perspective of input actors related to different seed companies. Moreover, although researchers are not part of an embedded unit of analysis, their inclusion contributes to the comprehension of the contextual environment in which the sunflower chain endeavor takes place. Among the farmers, two interviewees stood out due to their leadership position in the chain establishment process.

The interviewees were initially contacted by telephone to check their availability and then visited at their workplace. Information gathering were based on open-ended questions interviews adapted to each group of interviewees, aiming at understanding how the sunflower agri-food chain establishment process has been organized and which factors have enabled the involvement of actors from different chain segments in this endeavor. The interviews were audio-recorded with interviewees' permission and amounted to around 770 minutes (average lengths are shown in Table 8). The transcripts of the interviews amounted to around 130 pages, and interviews content analysis sought to identify the underlying causes for the successful sunflower agri-food chain establishment in MT. In this regard, the qualitative data analysis software MAXQDA (version 11, VERBI Software GmbH, Berlin, Germany) assisted the process of interview transcripts analysis, enabling the development of a coding system to simultaneously tag multiple interview quotes.

Table 8. Description of the recorded interviews

Interviewed Group	Number of Interviewees	Average Length of the Interviews (min)
Processing	1	100
Farming – leaders	2	65
Farming – others	12	12
Input suppliers	8	38
Local research	2	26
National research	2	20

4 Analytical description of the sunflower agri-food chain establishment process

4.1 Planning Stage

The planning stage of the sunflower agri-food chain in Mato Grosso took place in Campo Novo do Parecis in 2006. A set of factors triggered this collective farmer-initiative, including difficulties related to their unfavorable geographical location, high transportation costs, and low maize prices at that time, a collective desire for adding value to their agricultural production and for boosting the local economy, as well as role models from successful agro-industrialization experiences in other regions of MT, such as in Lucas do Rio Verde.

The sunflower chain opportunity identification and evaluation had a collective and self-organized approach. Local farmers led group discussions about different agro-industrialization investment possibilities for their locality and contracted out a feasibility study to support their decision-making process. Moreover, the reputation, experience, and leadership of a group member (hereafter called reference farmer) influenced the collective decision to focus the chain on a non-established crop, as was the case of sunflower in MT. In this regard, the group composition was a key issue for the whole chain establishment process. Mutual trust, and good professional and personal reputation were the main criteria for the members' selection. Furthermore, previous joint experiences and common goals influenced the group organization. The members were mostly farmers (about 40) from the micro-region of Parecis, in MT, owners of large-scale mechanized farms focused on the production of soybean, maize, and cotton. In addition, the group members had management experiences from other agricultural businesses, besides being involved in other innovative actions, like the introduction of maize popcorn cultivation in the state. Additionally, the leadership skills of some group members and the technical and commercial sunflower expertise of the reference farmer contributed to encourage members without experience with sunflower to join the endeavor. Table 9 highlights the main enabling factors underlying the planning stage of the sunflower agri-food chain. These factors are related to the organizing group, to the crop suitability, and to the market opportunity, which jointly led the group to decide for the establishment of the sunflower agri-food chain.

Table 9. Enabling factors for the planning stage

Category	**Enabling Factors**
Organizing group	(1) Mutual trust. (2) Previous joint experiences. (3) Participation of individuals related to the input segment of other crops (owners of farm supply retail stores and seed companies representatives). (4) Large-scale farm infrastructure. (5) Availability of own financial resources. (6) One reliable farmer with expertise on sunflower (reference farmer). (7) Leadership skills of some members. (8) Members' expertise in crop production. (9) Management experience.
Crop suitability	(1) Favorable soil and weather conditions for the cultivation of sunflower. (2) Additional crop with low need of specific investment (additional income and dilution of fixed costs). (3) Suitability of sunflower for the local farm production system. (4) Agronomic benefits (soil quality improvement related to crop rotation).
Market opportunity	(1) Market opportunity for sunflower oil—very few companies processed sunflower into oil in Brazil.

Nevertheless, there were risks of failure at the farming and processing levels related to the insipient development stage of the sunflower sector in Brazil at that time and related to the overall lack of experience of the group members on sunflower cropping and processing. Aware of this, the group defined a set of risk mitigation strategies to be applied in the next chain establishment stages (Table 10).

Table 10. Risks identified and risk-minimizing strategies defined by the group

Risk Sources	**Risk Mitigation Strategies**
(1) Low level of knowledge on sunflower production. (2) Inexperience in the vegetal oil processing segment. (3) Absence of an organized sunflower input segment in Brazil. (4) Low technological level in terms of seeds and agrochemicals in comparison with well-established crops (soybean and maize). (5) Very limited market structure on both the supply and demand side.	(1) Gradual development of the processing facility. (2) Investing in a multiple oilseeds processing plant able to process soybean (farmers' main crop) in case of shortage of sunflower. (3) Setting up the company as joint-stock company. (4) Organizing the diffusion of sunflower production knowledge.

4.2 Implementation Stage

The strategies defined in the planning stage were put in place during the implantation stage that began in 2006. Table 11 displays the structuring activities and the enabling factors for this stage. The organizing group was responsible for structuring the sunflower farming and processing segments. This included self-organizing activities to disseminate knowledge on sunflower cultivation among the group members. In this regard, the fact that sunflower was a non-established crop plant in Brazil coupled with the leadership, personal, and professional reputation of the reference farmer, placed this farmer as the focal point for the knowledge diffusion due to his greater experience in sunflower farming. Nevertheless, the knowledge diffusion had a collective approach supported by a favorable institutional environment of mutual trust, synergies, and previous joint experiences, as well as the agricultural expertise of all members of the group. Moreover, farmers led the construction of the processing facility on a shared self-financed basis, as well as the hiring and training of local labor force. In this regard, the small initial processing capacity, the incipient sunflower sector in Brazil, and the unfavorable geographical location of Campo Novo do Parecis limited company's capacity to hire skilled labor with experience in the business of sunflower. Therefore, at this stage, the building of competencies on industrial processing was a learning-by-doing process that involved the training of local labor force formerly from other agro-industrial sectors and a partnership with the company responsible for the development of the mechanical screw press for sunflower oil extraction.

The role of seed companies' representatives started at this stage with the initial establishment of sunflower seed companies' dealers in the region. This fact was a relevant step in the chain establishment process. Since sunflowers could be grown using the existing farm resources available for maize and soybean, the primary input needed for the chain establishment was the sunflower seed, which at that time was not readily available in that region. The actors were attracted by the expectation of profitable participation in the nascent agri-food chain due to the ownership of the processing company by farmers with individual large-scale farm production infrastructures and reliable social and professional reputation. Additionally, the fact that some group members operated in the input segment of other crops facilitated the entry of sunflower seed companies' dealers into the region.

The implementation stage lasted until 2008. The main reason for its relatively large duration was an operational problem that required a new investment and delayed the conclusion of the processing plant. During this situation, another company that operated in the sunflower seed and processing segments in southern Brazil supported the farmers' initiative by buying the entire sunflower production while their processing facility was not finished.

Table 11. Implementation of the sunflower agri-food chain segments

Chain Segment	Structuring Activities	Enabling Factors
Farming	(1) Diffusion of sunflower production knowledge. (2) Provision of feedstock for the processing company.	(1) Expertise and reputation of the reference farmer. (2) Teamwork culture. (3) Mutual trust and commitment of the group members. (4) Low need of specific investment (synergies).
Processing	(1) Construction of the processing facility (20 tons/day). (2) Hiring and training of local labor force.	(1) Availability of financial resource. (2) The commitment of the group members. (3) Managerial skills. (4) Support from another sunflower processing company.
Input	Initial establishment of sunflower seed companies' dealers in the region.	(1) Group members' reputation. (2) Farms' large-scale production capacity. (3) Group members from the input sector of other crops. (4) Synergies with other crop business units.

Regarding the governance mechanisms, relational governance and informal contracts were the means adopted for coordinating the economic activities between farmers and the processing company (Table 12). Contracts specifying a set of items organized the provision of sunflower among members. However, the contracts were, in general, simple communication forms (e.g., an e-mail) instead of formal written contracts. This governance arrangement was possible due to the trusting relationships within the group as well as the members' engagement and commitment to the agri-food chain establishment, which minimized transaction costs related to agents opportunism, lessening the risk of transaction failure. In that sense, social control and self-enforcing mechanisms for transactions among group members made trust the main transactions governance form at that stage.

Table 12. Transaction coordination mechanisms

Governance Forms	Contract Items
(1) Relational governance (trust). (2) Informal contracts.	(1) Sunflower planted area (ha). (2) Price defined before the beginning of the season that sought to guarantee sufficient profitability for farmers and for the company. (3) Payment in more than one installment after delivery. (4) Feedstock delivery done by farmers.

4.3 Growth Stage

The growth stage started in 2008 with the beginning of the company's commercial operation in the sunflower edible oil market for industrial consumers. Table 13 lists the outcomes and the enabling factors for this stage. The three chain segments have consolidated in the region, which became the major center of sunflower production and processing in the country.

Table 13. Outcomes of the growth stage and their enabling factors

Outcomes	Enabling Factors
(1) Expansion of the processing capacity (20→60→100→600 tons/day) over six years. (2) Consolidation of the company as the main national sunflower processing company.	(1) Cohesion, commitment and consistency of the group overtime. (2) Collective ownership guaranteed sufficient degree of feedstock security. (3) Managerial skills of the group members in charge of heading the company. (4) Group members' resource availability coming from other crops/businesses. (5) Entry of an industrial shareholder. (6) Public policy of fiscal incentive for industrialization that allowed the access to credit and tax conditions in advantageous terms. (7) Consolidation of the farming segment and the local input segment. (8) Entry of non-shareholders sunflower suppliers.
(1) Consolidation of the company in the domestic market of sunflower unrefined oil for food industry consumers.	(1) Product quality recognized by the buyers. (2) Lower competition than in the market of refined sunflower oil for final domestic consumers. (3) Company's ability to provide small loads to its clients.
(1) Development of a regional market for sunflower seed cake/meal for livestock feed.	(1) Regional demand. (3) Attractive price in relation to soybean meal. (4) Farmers social networks and managerial skills.
(1) Consolidation of the region as main national sunflower producing area. (2) Expansion of the sunflower production knowledge.	(1) Cohesion, commitment and consistency of the group. (2) Large agricultural area available in the region. (3) Large-scale and mechanized farm infrastructure. (4) Consolidation of the input and processing segments. (5) Knowledge diffusion activities organized by farmers, processing company and seed providers.
(1) Consolidation of a local sunflower input segment (five seed companies set up local dealers in the region).	(1) Consolidation of the processing and farming segments.
(1) Entry of non-shareholders sunflower suppliers (replacement of informal contracts by formal ones).	(1) Support provided by stakeholders from the input segment—provision of technical assistance and linking farmers to the processing company via contract. (2) The role model from farmers of the organizing group, (3) Synergies (additional crop with low need of specific investment → additional income and dilution of fixed costs). (4) Consolidation of the agri-food chain.

The interdependency of the chain segments is highlighted at this stage since the consolidation of each segment enabled the consolidation of others segments in a kind of "feedback loop" necessary for the development of the agri-food chain. Furthermore, the strategies defined in the planning stage proved to be effective in the growth stage. Given that the operational and administrative processing company's personnel had no previous experience in the business of sunflowers, the strategy of gradual development enabled the progressive obtainment of sunflower processing and market expertise. Moreover, the knowledge diffusion activities achieved the goal of spreading sunflower production knowledge among farmers; and the setting up of the company as a joint-stock company shared the risks and facilitated the entry of an industrial shareholder that resulted in the last and most significant expansion and modernization of the processing company in 2014. The industrial shareholder acquired 30% of the company's capital and supported the investment in a modern oilseeds solvent extraction plant capable of processing up to 600 tons of sunflower per day. Moreover, this new shareholder brought technical expertise in the process of oilseeds solvent extraction to the group, which, until then, operated exclusively with a mechanical screw press. The group of farmers, in turn, maintained the majority control of the company and accounted for most of the investment. In this sense, a program of public incentive for industrialization was also decisive for the expansion of the company, since it provided the members of the group with financial credit and fiscal conditions on advantageous terms.

With the successive expansions of processing capacity, non-shareholders farmers started to supply sunflower to the company. Despite the successful establishment of sunflower cultivation in the region, this crop has faced some technological limitations (e.g., concerning seed adaptability and agrochemicals availability), especially in comparison with well-established and competing crops, as maize. This fact have limited the interest of some group members (owners of large farms) to allocate large shares of their land to sunflower (as a risk-minimizing strategy). Therefore, the entry of external or non-shareholder suppliers sought to meet the demand increase generated by the growth of the processing company. In this respect, the participation of stakeholders from the input segment has played an important role for the attraction of new sunflower suppliers. Those actors link new sunflower suppliers to the processing company, being responsible for providing farmers with inputs (especially seeds), technical assistance, and contract within an environment highly influenced by social networks and trust. The active participation of input segment actors in the sunflower agri-food chain operation is another indication of its effective establishment and provides a win-win situation. While these agents benefit from the sale of inputs, non-shareholder farmers benefit from the technical assistance received and the connection with the processing company, and shareholders-farmers benefit from the sunflower business consolidation. Moreover, farmers' majority participation in the ownership of the processing company gives them the role of coordinating the sunflower agri-food chain, being responsible for relevant operational and strategic decisions (e.g., the decision to expand and modernize the processing company). With the entry of the industrial shareholder and the non-shareholders sunflower suppliers, formal contracts replaced the informal ones, although relational governance has remained as a complementary governance structure.

The consolidation of the sunflower agri-food chain in MT is also related to the market in which the company decided to operate. Farmers' decision to target the market of non-refined sunflower oil for food industry consumers appears to have been the most viable one considering the limited sunflower oil market structure and the gradual development approach adopted by them. By targeting this market, the company avoided competing with large and well-established food companies that dominate the market of sunflower refined oil for final domestic consumers. Furthermore, the high investment necessary to enter in the sunflower processing sector competing with big players would make the gradual development approach not suitable, precluding the establishment of farmer's company. Moreover, the buyer power of its clients is lessened, due to the insufficient national supply of sunflower oil, and the comparative advantage of farmers' company regarding its ability to supply small volumes of sunflower oil to its customers, which alternatively would have to import larger amounts of the product mainly from Argentina. Additionally, as the food industry has rigorous feedstock quality standards, the recognition of the quality of the oil regarding fatty acids components and oil purity by the buyers since the beginning of company's commercial activities was essential for company's consolidation in the market. Finally, the development of a regional market of sunflower seed cake/meal (sunflower oil byproduct) for livestock feed also contributed to the chain establishment due to the generation of additional revenue.

Despite its successful development, the sunflower agri-food chain in MT has faced challenges over the growth stage period. The main one refers to the instability in the sunflower production area over the years. This instability is related to the fact that the sunflower remains as a non-established crop, therefore, being highly subjected to land use competition with maize. The latter crop is also grown in the second season after the harvest of soybean; however, maize is a well-established crop with better market liquidity and technological conditions in comparison with sunflower. Thus, as farmers are usually more willing to grow maize, especially in years of soaring prices, sunflower becomes comparatively less profitable than maize. Consequently, the company faces difficulties in generating sufficient value (regarding sunflower price) for its feedstock suppliers, especially for non-shareholders farmers. Moreover, high energy costs and the long distance of the processing company to the main consumer markets (over 1500 km) associated with poor road conditions have affected the company's competitiveness. Additionally, the sunflower oil demand side limitations combined with macroeconomic conditions have also impacted the sunflower chain development in the last four years. Once sunflower oil is part of a niche market within the edible vegetable oil sector in Brazil, the country's economic performance affects directly the demand for this product, which is two to three times more expensive than soybean oil (main vegetable oil consumed in Brazil). Furthermore, given the insufficient domestic production of sunflower oil in Brazil, in periods when the Brazilian currency (Real) appreciates against the US dollar, sunflower oil importation costs decrease, favoring imports from Argentina—the main producer in South America.

5 Discussion

The process of the sunflower agri-food chain establishment in Mato Grosso has proven to be a sustainable/lasting and complex social-economic endeavor stemming from a set of connected driving forces composed of entrepreneurial skills, social network, resource availability, and crop suitability. These components favored horizontal cooperation and downstream collective vertical coordination, allowing farmers to independently identify and develop the opportunity related to the sunflower agri-food chain, overcoming barriers associated to the initial development stage of the sunflower sector in Brazil, besides reducing risks of transaction failure and favoring company's consolidation in the market.

Triggering events provided the initial stimulus for downstream collective vertical integration, which, combined with the driving forces, favored the establishment of a sunflower agri-food chain in the micro-region of Parecis, MT. Figure 9 summarizes the triggering events as well as the driving forces, their sources, and their outcomes for this sustainable collective entrepreneurial agri-food chain endeavor. The set of driving forces enabled a short, but efficient, planning stage, facilitated the chain segments structuring and a knowledge diffusion scheme in the implementation stage, besides having ensured the chain continuity and expansion in the growth stage.

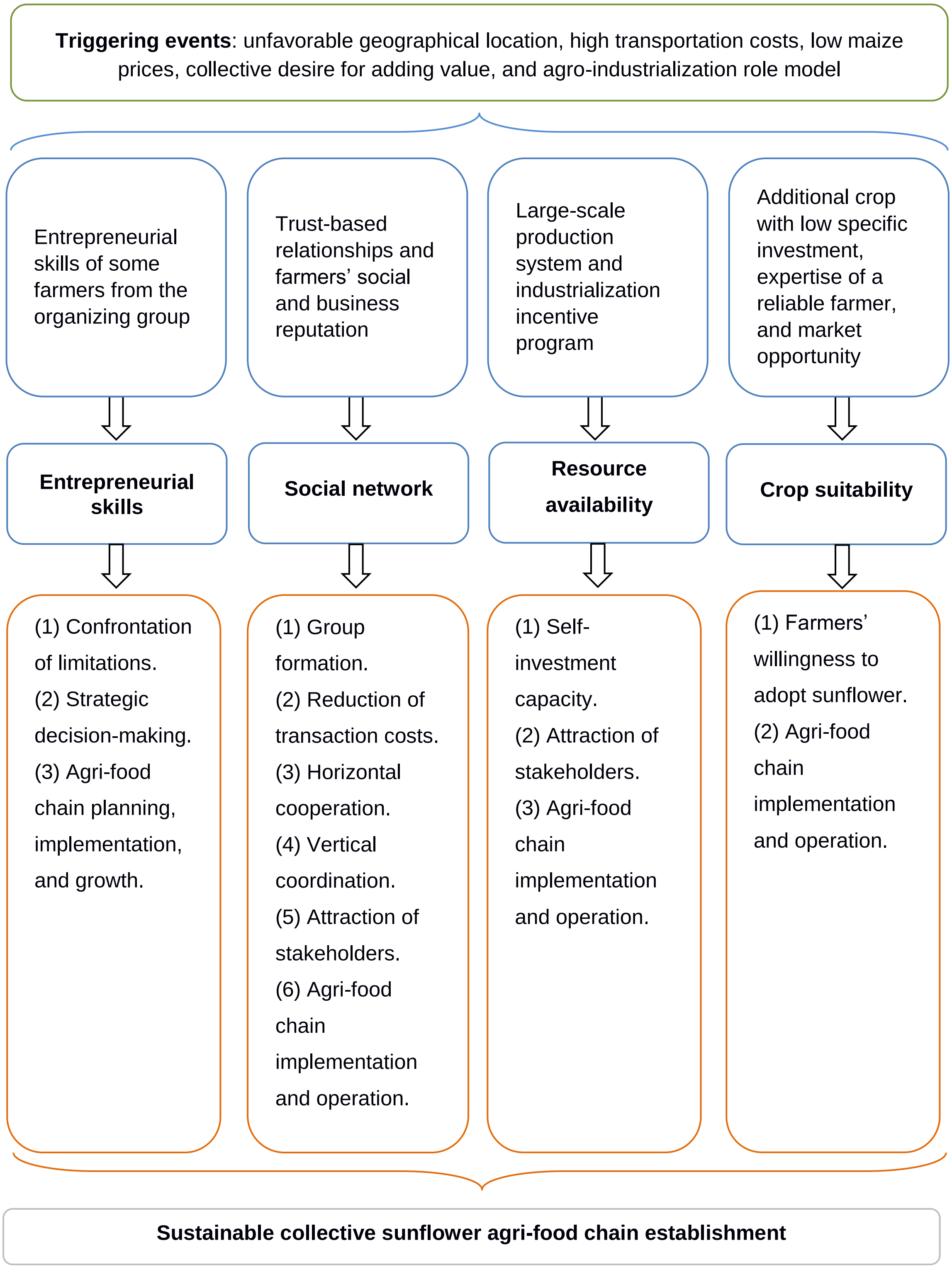


Figure 9. Underlying reasons for the sustainable collective sunflower agri-food entrepreneurial endeavor in Mato Grosso

The entrepreneurial skills component led the group confronting limitations (e.g., unfavorable geographical location), adopting a strategic decision-making approach (e.g., definition of chain focus and risk-mitigating strategies), and supporting the agri-food chain planning, implementation, and growth. In this regard, the main entrepreneurial skills emerged from the process were leadership, initiative, the ability to detect and develop opportunities, planning capacity, a forward-looking vision, the willingness to take calculated risks, the perseverance, determination and ability to react to frustration, a network of contacts, business field experience and market orientation, as well as management skills. Conversely, the lack of stakeholders' entrepreneurial orientation hinders the development of agri-food chains, such as that observed in organic citrus chains in Greece (Anastasiadis and Poole, 2015). Furthermore, the sunflower case study points to the benefits of collective entrepreneurship (Martìnez, 2004), since the high entrepreneurial skills of some members had a positive spillover effect on other members with less entrepreneurial skills. This has been made possible by the social network component.

The sunflower case study confirms the idea that social relations embed and shape economic actions (Granovetter, 1985; Uzzi, 1997). In this regard, the composition of the organizing group based on mutual trust and common goals was a key factor that assured members' commitment and cohesion over time. It was fundamental for the agri-food chain implementation and operation. The importance of members' selection was also observed in collective agricultural businesses in Sri Lanka (Rosairo and Potts, 2016), where the selection of entrepreneurial farmers to run agricultural enterprises was indicated as a key factor for a company's sustainable operation. This is highlighted in the sunflower case by the paramount influence that a few members had on the chain establishment process due to high levels of leadership capacity, managerial skills, and technical expertise in such a way that, without them, the chain endeavor might not have occurred. Furthermore, the group members' formation highlighted the role of previous successful experiences (long-term relationships), and social and economic reputation as trust-builders (Trienekens, 2011; Galaskiewicz, 2011; Hartmann et al., 2010; Furlong, 1996). Moreover, members' good reputations contributed to attract other stakeholders to the sunflower agri-food chain in the implementation and growth stages. Additionally, farmers' trustful relationships reduced transaction costs, encouraging them to jointly invest in specific assets (Barney and Hansen, 1994; Furlong, 1996), besides having favored horizontal cooperation (e.g., in terms of knowledge diffusion process) and vertical coordination, since the group trusted the members in charge of leading the company (Galaskiewicz, 2011; Keefer and Knack, 2005; Furlong, 1996). The present case study also evidenced that trust can be the main primary governance structure (Uzzi, 1997) in early chain development stages while the economic activities are restricted to group members.

Nevertheless, the agri-food chain expansion required the adoption of formal contracts to lessen the risk of transaction failure.

The importance of resource availability for agricultural chains development (Trienekens, 2011) was highlighted in the sunflower case study due to its internal driven approach without support from intermediary organizations. In this regard, the fact that group members being large-scale farmers with other income sources than sunflower allowed them to bear implementation and operational costs and risks, especially in periods of company's financial difficulties. Furthermore, group members' large-scale production structure contributed to attract other stakeholders, since it offered certain investment security to sunflower seed companies' dealers that settled in the region and to the industrial shareholder that joined farmers' initiative. Moreover, the present case shows the importance that public incentive programs for industrialization have on supporting business expansion, by the provision of credit with low interest rates.

The suitability of sunflower both at the farming and processing levels was another underlying reason for the successful chain establishment. Although sunflower is a non-established crop in Brazil, the following aspects guaranteed at least a minimum level of farmers' willingness to adopt sunflower over time: (1) its dovetail with the local farm production system, not affecting farmers' main income source (soybean); (2) its low level of specific investments, sharing the productive resources available for soybean and maize; (3) the previous cropping experience of a reliable farmer with remarkable leadership capacity; and (4) the knowledge diffusion schemes. At the processing level, the suitability of sunflower could be seen by the operation in a market segment with low domestic competition that facilitated the company's consolidation in the market. Thus, crop suitability proved to be an essential factor for chain implementation and operation over time.

The crucial components for successful business endeavors are a good opportunity, good entrepreneurs, and availability of resources needed to initiate and to sustain the business growth (Bygrave, 2010). These three components could be seen in the sunflower agri-food chain endeavor in MT, having been enabled by the driving forces that led its establishment process. In contrast, this has not been the case of other agricultural chain endeavors, especially among smallholder farmers. For instance, the castor bean biodiesel chain in Minas Gerais, Brazil is an example of how the lack of entrepreneurial approach (by the decision-makers from intermediary organizations and the farmers), weak social networks (lack of horizontal organization), resource scarcity, and crop inadequacy at the farming level can hinder an agricultural chain development even with favorable demand-side conditions (purchase and price guarantees) (Watanabe and Zylbersztajn, 2012).

The findings from the sunflower case study suggest that the collective establishment of agri-food chains is a complex endeavor, especially if led by outside actors (e.g., intermediary organizations). The main reason for this complexity is that the driving forces underlying the successful agri-food chain establishment process are factors difficult to be framed or fostered. The development of entrepreneurial skills, in other words the idea of "making" entrepreneurs, is a topic that has not achieved a consensus in the literature on entrepreneurship. Nevertheless, it seems to prevail the idea that "making" entrepreneurs is possible and depends, on the one hand, on a certain predisposition to entrepreneurship, in terms of personality traits, and, on the other hand, on the access to proper tools to execute entrepreneurial endeavors, which can be obtained by training and from an enabling environment (Knudson et al., 2004). Although possible, this is undoubtedly a complex task, since there are multiple skills related to an entrepreneur, including technical, managerial, strategic, and market abilities (Kahan, 2012). Regarding social networks, evidence suggests that cooperation or willingness to cooperate is, in part, a cultural element (Watanabe et al., 2012). Consequently, building up a propitious trustful environment for mutual horizontal and vertical collaboration among potential partners, essential for collective agri-food chain endeavors, is a time-consuming task (Van Der Vorst, J.A.I. J. et al., 2007). Finally, although financial constraints are a strong barrier for any business development, including agricultural ones (Rosairo and Potts, 2016; Trienekens, 2011), the sunflower case study findings indicate that the provision of a physical structure appears as the most straightforward task for the agri-food chain establishment process, in comparison with the complexity of developing entrepreneurial competency and building trustful social networks among potential agri-food chain actors.

6 Conclusion

Entrepreneurial skills of large-scale farmers within a social network based on trust and personal and professional reputation, coupled with crop suitability, are the main underlying reasons for the successful sunflower agri-food chain endeavor in the micro-region of Parecis, Mato Grosso, Brazil. The analysis suggests that the development of new sunflower agri-food chains could take place among soybean farmers from other agricultural regions in MT, due to the availability of arable land and resources suitable for introducing sunflower as a second-season crop, and a similar cultural background of pioneering and collective actions that lessen transaction costs and individual financial requirement, favoring horizontal cooperation and collective investment. This fact indicates the existence of a supportive institutional environment for the collective establishment of new sunflower agri-food chains in MT. In this regard, the sunflower chain in Parecis serves as an important role model for soybean farmers from other agricultural regions in MT interested in engaging themselves in a collective sunflower agri-food chain endeavor.

Among the several enabling factors related to the four driving forces components identified in the sunflower chain establishment process, in case of a collective agri-food chain development, special consideration should be given to the formation of a cohesive and committed organizing group comprised of trusted individuals, preferably with previous collaborative experiences, and with at least one individual of recognized leadership ability, besides technical, managerial, and market expertise related to the crop or livestock focus of the agri-food chain.

The existence of a favorable institutional environment for the expansion of sunflower agri-food chains in MT, and the influence of land use competition on the sunflower production area indicate the need of investigating and estimating the potential for the expansion of sunflower diffusion to different agricultural regions of MT. This is the topic of the next section.

SECTION 3 – A bio-economic model-based assessment of sunflower adoption in double-cropping systems in Mato Grosso, Brazil[5]

1 Introduction

One of the major challenges that our society currently faces is to ensure the sustainable supply of food in a scenario of shrinking natural resources, and a rising global population and wealth. In this context, the replacement of animal protein by plant protein in human nutrition is seen as one possible way of achieving more sustainable agri-food systems, especially because plant production uses fewer natural resources and is less taxing on the environment than livestock production (Aiking, 2014; Sabaté and Soret, 2014; Vainio et al., 2016). Moreover, although soybean leads the market segment of plant protein ingredients, with about 50% of its volume share (Frost & Sullivan, 2012), food manufacturers, particularly in Europe, have invested in the development of alternative sources of plant protein due to the growing use of genetically modified soybeans, which have a negative image among consumers (Pickardt et al., 2015; Frost & Sullivan, 2012). Against this background, sunflower emerges as a promising feedstock for plant protein ingredients (Pickardt et al., 2015; Weisz et al., 2009; González-Pérez and Vereijken, 2007; González-Pérez et al., 2002).

Sunflower is adapted to Brazil due to agronomic and physiological traits that enable its cultivation under different agro-climatic conditions in the country (Castro and Leite, 2018). Moreover, recent studies have suggested that the introduction of sunflower can be a way of improving the agricultural production systems in Brazil, particularly in the state of Mato Grosso (MT), which leads the national production of soybean, maize, cotton, and sunflower using double-cropping systems. Soybean-sunflower systems can lessen environmental impacts related to human toxicity, freshwater toxicity, freshwater eutrophication, climate change, and terrestrial acidification impacts in comparison with monoculture systems (Matsuura et al., 2017). Moreover, sunflower can contribute to the management of certain nematodes infestation, which is a severe problem in grain producing areas in Brazil, besides providing a viable additional farm income source, different from other non-commercial alternative cover crops available for farmers, such as millet, *Crotalaria spectabilis*, and *C. ochroleuca* (Dias et al., 2016).

[5] Marcelo Carauta, Anna Hampf, Christian Troost, Affonso Libera, and Thomas Berger contributed to the development of this section.

Despite the agro-climatic suitability and the potential benefits of sunflower, its area is still incipient in Brazil. The land use for sunflower in the main producing state (MT) accounts for approximately 55,000 hectares on average over the last ten years – which is approximately 2% of maize land use (CONAB, 2018). However, the potential participation of Brazil, particularly MT, in the upcoming market of high-quality sunflower protein ingredients related to the (presented in the previous sections) can drive the sunflower sector expansion in Brazil in the near future. Nevertheless, this participation is subjected to the availability of sufficient feedstock supply, which is one of the main determinants for the innovator's decision on whether and how to implement a food innovation (Zilberman et al., 2017; Du et al., 2016).

To date, there are still no quantitative studies estimating the potential sunflower production expansion, taking into account typical socio-economic, technological, and biological aspects of double-cropping systems prevailing in MT. Moreover, little is known about the impact of sunflower diffusion on farm income and land-use intensification. Furthermore, no previous study in MT has comprehensively investigated how crop yields respond to socio-economic and environmental conditions.

Therefore, this section aimed at examining the potential for sunflower diffusion into double-cropping systems in MT in view of the possible implementation of food innovations related to sunflower in Brazil. This objective involved: (1) simulating the diffusion path of sunflower in MT with the identification of barriers to its adoption, (2) estimating the potential for sunflower production in MT, and (3) evaluating the economic impact of sunflower adoption at farm-level. To achieve these objectives, an integrated assessment (IA) approach was applied, combining an agent-based model (ABM) with a crop growth model. This approach takes into consideration a heterogeneous farming population, economic incentives, and socio-economic/technological/environmental constraints.

2 Methodology

2.1 Study region

The federal state of Mato Grosso (MT) is the third largest state by area in Brazil. It is home to a unique share of wildlife habitats with three different ecosystems (Cerrado – savanna vegetation, Amazon rainforest, and Pantanal – wetlands) and is one of the largest global agricultural production regions. Currently, MT leads the nation in soybean, maize, cotton, sunflower and beef cattle production (CONAB, 2018).

Agricultural systems in MT consist of mainly large-scale agriculture with highly mechanized double cropping systems. Mato Grosso’s main comparative advantage is its climate and topography. The well-defined rainy season allows farmers to grow two crops per agricultural year while its flat land permits the extensive use of machineries. The first cropping season begins in September/October with the onset of the rainy season, whereas the second one starts from January/February. The main double cropping systems observed in MT are soybean-maize, soybean-cotton, and cover crop-cotton, while soybean-sunflower is concentrated in the western region of MT, particularly in the municipality of Campo Novo do Parecis.

2.2 Integrated modeling approach

Our IA approach simulates farm-level decision-making by combining an agent-based model (ABM) with a crop growth model. This coupling allows specific local environmental conditions to be considered in a farmer’s decision-making. Thus, our simulations account for heterogeneity and interdependencies among agents and their environment. This is very important in large/diverse regions where the use of average indicators might lead to ineffective policy interventions (e.g., a policy beneficial for typical agents but unfavorable for other agents).

Our ABM was implemented using the software package Mathematical Programming-based Multi-Agent Systems (MPMAS). MPMAS uses whole-farm mathematical programming (MP) to simulate farmers decision-making process (Schreinemachers and Berger, 2011). MP-based ABM are a well-established approach for studying human-environmental systems (e.g., land-use systems) and coupled human and natural systems as well as to analyze complex systems composed of socio-economic and biophysical components, such as agricultural systems (Berger and Troost, 2014; An, 2012; van Wijk et al., 2014). MPMAS uses Mixed Integer Programming (MIP) to simulate farmer decision-making in three stages: (1) investment decision, which occurs at the beginning of a cropping season and agents decide, for example, which machinery to buy; (2) production decision, which occurs before sowing and agents decide which crops to grow; and (3) consumption decision, which occurs after harvest and agents decide how much to sell, withdraw or save for future periods. In every simulation period, which corresponds to one real-world agricultural year, MPMAS maximizes each model agent’s expected farm income subjected to his individual land, labor, machinery and cash endowments as well as site-specific constraints (e.g., soil and weather characteristics) for each scenario. At the investment and production stages, agents in MPMAS plan according to expected local yields and prices; at the third decision stage (consumption), agents update their decision based on actual crop yields – simulated by MONICA – and crop prices received for a given year. The ODD (Overview, Design concepts, and Details) protocol describing MPMAS software architecture and equations can be found in Schreinemachers and Berger (2011).

The second component of our IA application is the process-based model for nitrogen and carbon in agro-ecosystems (MONICA). MONICA has been used to simulate crop yield responses to different soil types, cultivars, nitrogen fertilization rates, sowing dates, management practices and climatic conditions (Hampf et al., 2018; Battisti et al., 2017; Nendel et al., 2014). A detailed description of MONICA and its specification can be found in Nendel et al. (2011). For this current application, MONICA was parameterized according to Figure 10 (in section 2.3).

MONICA calibration for soybean and maize was done using farm-level data from 32 different municipalities between 2007 and 2013, with 851 observations for soybean and 576 for maize (APROSOJA, 2018). Cotton was calibrated using a private survey from Céleres with 175 yield observations at farm level from 2010 to 2013 (Céleres, 2018). Field trials testing the performance of eight different sunflower cultivars on two different experimental sites in Campo Novo do Parecis between 2013 and 2015 were used for sunflower calibration (Birck et al., 2017). A random sample of two third of the datasets were used for calibration purposes and one third for model validation (see section 3.1). Crop cultivars were calibrated based on observed climate data from five different meteorological stations in MT (Canarana, Diamantino, Matupá, Poxoreo and Sapezal), containing daily weather records of temperature, precipitation, radiation etc. between 1999 and 2015 (INMET, 2017). Soil properties (e.g., silk, clay content, C/N ratio, bulk density) were then taken from the soil database of Cooper et al. (2005).

We advanced the modeling approach of Carauta et al. (2017) and Hampf et al. (2018) in five aspects. First, we implemented agent interactions through the innovation diffusion module. Second, we included sunflower as a new agricultural practice. Third, new management practices for maize production were also incorporated. Fourth, agricultural input prices, as well as crop prices, were updated to a more extended time series to capture mid-term effects. Last, given the availability of a recent weather dataset with a longer time frame (1999-2015), new crop yields were simulated.

Following the sampling procedure of IMEA (2010), we parameterized our model for five macro-regions in MT (Northeast, Southeast, West, Mid-North and South Central), which produce almost the entire agricultural output of the state. Following the Monte Carlo sampling approach of Berger and Schreinemachers (2006), a statistically consistent agent population was created with 720 agents using empirical data from the latest Brazilian Agricultural Census (IBGE, 2006) and the agricultural survey from the Mato Grosso Institute of Agricultural Economics (IMEA, 2016). Crop production requirements correspond to the 2015/2016 cropping season and were estimated from several sources, such as (1) IMEA agro-economic survey (IMEA, 2016), (2) field survey (described in section 2.3), and (3) local field experts. Six different soil types were identified and assigned to each model agent based on the official maps of the socio-ecological zoning produced by the Mato Grosso State Secretary of Planning (SEPLAN, 2011).

Each agent's MIP formulation contained 2,045 decision variables (including 182 integers) and 1,741 constraints, which MPMAS formulates for each agent, decision stage, period, scenario and design point (model repetition for uncertainty analysis). To avoid computational limitation and to speed up simulation run time, each MIP was solved using the IBM-CPLEX solver - calibrated specifically for this study - and parallel simulations were run on the high-performance computer cluster of the state of Baden-Württemberg, Germany.

2.3 Agricultural practices observed in Mato Grosso

The agricultural production practices specified in our modeling approach correspond to the most common agricultural commodities found in MT: soybean, maize, cotton, and sunflower. Model agents can choose between multiple crops, crop rotation schemes, sowing dates, maturity groups, fertilization rates, seed varieties, and soil types. Figure 10 summarizes the different variables taken into consideration in our model.

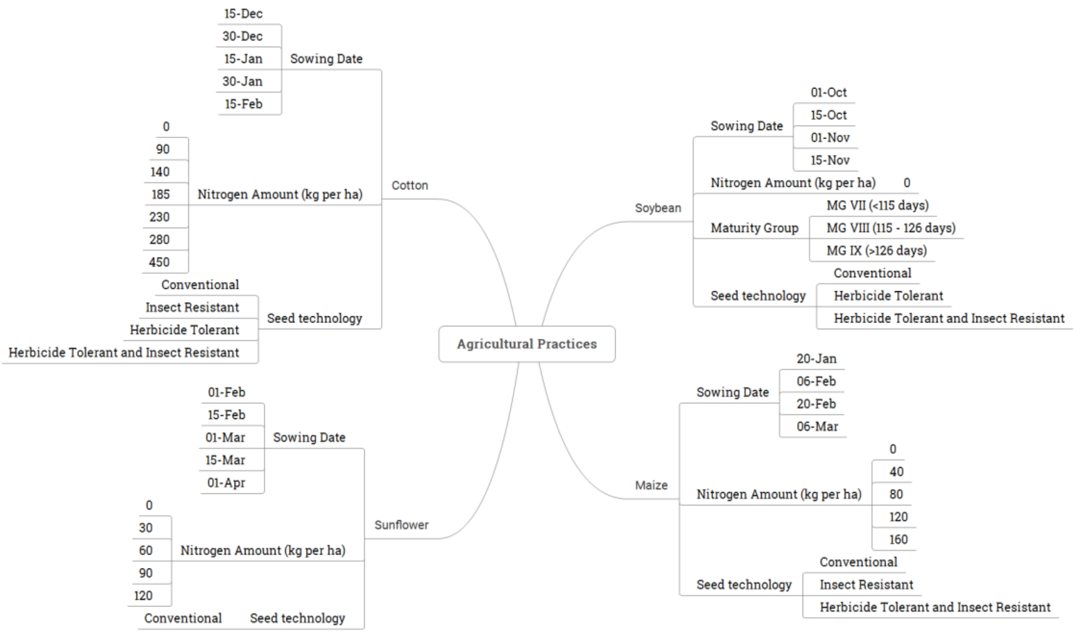


Figure 10. Overview of agricultural practices considered in the simulations

A fieldwork was carried out in five municipalities of MT (Campo Novo do Parecis, Brasnorte, Sapezal, Campos de Júlio, and Sorriso) between April and July of 2016 to identify the main factors associated with the recent development of the sunflower production and processing in MT. On this occasion, production and post-harvest costs were estimated through local sunflower expert – farmers, technical assistance providers, researchers, industry representatives, and seed dealers.

In total, 254 production activities were estimated and attributed to each model agent for each year and scenario. Combined with region-specific soil fertility constraints, there were more than 2500 crop-mix options at farm level. Since favorable climatic conditions enable farmers in MT to grow two crops in the same agricultural year (in a double cropping system), the complexity of a farmer's decision-making process increases even further, as crops can be combined with several possible double-cropping combinations.

2.4 Model features

Our simulations include region-specific socio-economic constraints. This means that agents in different regions use different types of pesticides and select different intensity levels of machinery use. Also, agents in different regions face different input/selling prices as well as different transportation costs. To capture mid-term effects of policy intervention and technology diffusion, local market prices were estimated from IMEA for each macro-region for a period of four years (2014-2017).

Furthermore, our production cost also takes into account crop variety and maturity group. As an example, crops with different seed variety require different pesticides (active ingredients), pesticide applications and quantities. Similarly, crops with longer maturity cycles require more pesticide applications. Moreover, each agricultural practice requires different field operations and each field operation has its own input, labor, and machinery requirements. Therefore, a crop calendar with a weekly resolution was created for each agricultural practice to capture the timing of agricultural activities as well as to simulate agents' resource allocation of machinery, agricultural inputs, and labor. Rules determining crop rotations were parameterized in the MIP as constraints, which are also linked to the crop calendar. In total, our production cost considers 165 agricultural inputs (e.g., fertilizers, seeds, herbicides, insecticides, and fungicides), 13 field operations (e.g., harrowing, ploughing, soil correction, weed control, sowing, spraying, and harvesting) and three post-harvest costs (e.g., transporting, processing and storing).

Field operations are subjected to weather conditions, so months with high precipitation have less field days, which then reduces the monthly supply of labor and machinery. Agents in our model can hire three types of labor (manager, machine operator, and field assistant), who may have permanent or temporary contracts. Farm owner is assumed to work as a manager, and each manager is assumed to be responsible for an area of 3,000 hectares. There are 16 machine types included in the model, and five of them (seeders and harvesters) can be rented (but with limited hours due to local market constraints). Agents can purchase machinery using their own funds or with governmental credit lines. Model agents can access several credit lines, which differ by interest rate, credit conditions and the purpose of the credit lines. For financing input acquisition, model agents can choose from federal credit lines (usually with lower interest rate but restricted credit limit), resellers, or multinational enterprises. Farm agents can also access federal credit lines for machinery acquisition; a more unconstrained credit line is accessible (with a higher interest rate and short time span) as working capital and can be freely used (e.g., to pay wages, hire workers or buy additional inputs if needed).

Direct interactions between households are modeled through the technological innovation model feature, where agents share information about new technologies. The technology innovation model component is based on the theory of diffusion of innovations developed by Rogers (2003) and is described by Schreinemachers and Berger (2011). Agent interactions are implemented as a frequency-dependent contagion effect: the more agents adopt a technology, the more it becomes accessible to others. The agent population is subdivided into five adopter categories (innovators, early adopters, early majority, late majority, and laggards). In the beginning, only innovators have access to the new technology (e.g., for this current situation, sunflower cultivation). Only when agents in the more innovative segment have adopted the new technology, it becomes accessible to agents in the less innovative segment.

Once an agent adopts a new technology (e.g., sunflower) or a complex production system (e.g., cotton) for the first time, he faces a learning cost, which was parameterized to simulate (1) the initial investment with specialized machinery, and/or (2) the yield gap between a novice and an experienced farmer. Figure 11 depicts the learning curve in terms of relative yield, which was estimated with local experts and technical advisors.

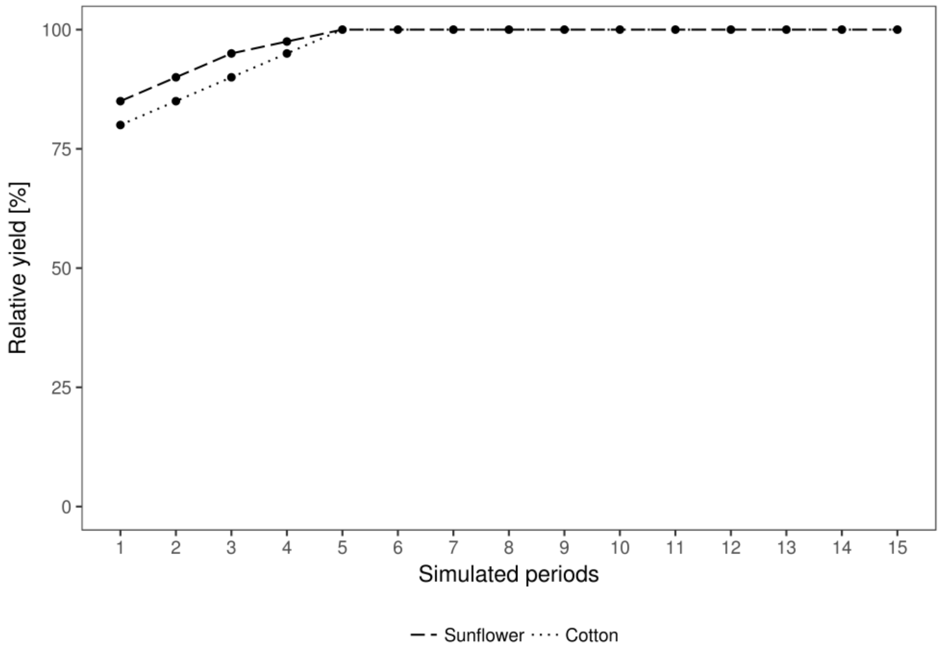


Figure 11. Relative yield factor due to learning processes

At the end of each simulation period after harvest, each agent must secure a minimum consumption threshold to fulfill his livelihood. Otherwise, he will exit the simulation. Furthermore, if there is a cash surplus, each agent spends a share of his income on consumption (that depends on the performance of the household enterprise).

Model agents must pay different types of taxes and charges related to production, sales, and land-use. Taxes were included in MPMAS following the current legislation. If farm agents have more cash than they need, they can put it into the bank to receive interest for short-term deposits. The remaining cash is carried over to the next period to maintain the production cycle.

At the beginning of the simulation, land (owned and rented) is assigned to each agent according to the latest agricultural census. If an agent receives rented land, it must pay the rent until the end of the renting contract. In exceptional cases, an agent might cancel a renting contract before it is completed (e.g., cash reserve is insufficient, and all credit limits were reached), but shall receive a utility penalty in his objective function. Model agents can also rent out their owned land for a discounted price lower than the market price (this prevents agents with lower gross margins to rent out whole farms since there is no information about how much land can be rented out).

3 Model validation and simulation experiments

3.1 Model verification and validation

At the model verification stage, we ran several tests to check if the code has been thoroughly tested for programming errors and to evaluate whether our model performs as designed. A face validation of model and simulation results was done with experts from key institutions in MT and with professionals with in-depth knowledge of MT. To that, we have established partnerships with key institutions in MT, such as Brazilian Agricultural Research Corporation (EMBRAPA), Mato Grosso Agriculture Economic Institute (IMEA), Federal University of Mato Grosso (UFMT), Federal Institute of Mato Grosso (IFMT), and Soybean and Maize Producers Association of Mato Grosso (APROSOJA).

At the model validation stage, we evaluated how well model output matches the corresponding observed values. We assessed the reliability of our simulations on both models, MPMAS and MONICA. Since our MPMAS simulates both the decision of individual farms and the agricultural land-use patterns of the study area as a whole, we used two benchmarks for model validation: (1) for farm-level validation, we compared the simulated land use of single farms with typical farms from IMEA’s survey (IMEA, 2016); (2) for regional-level validation, we compared our simulated land use (aggregated from all farms in the study region) with the ones observed in the corresponding agricultural survey from the Brazilian Institute of Geography and Statistics (IBGE, 2018).

As suggested by Troost and Berger (2015), to avoid overfitting and deterioration of model’s out-of-sample properties, we did not calibrate the model for a perfect fit but instead assessed model efficiency by evaluating the full space spanned by the uncertain model parameters. Table 14 presents the model’s goodness-of-fit for MPMAS simulations at the farm and regional levels, calculated based on standardized absolute errors (ESAE). As it can be seen, the results of our empirical validation suggest a very good model performance, with validation indices close to unity on both levels of aggregation.

Table 14. MPMAS model validation

	Average	**Min**	**Max**
Farm Level			
Typical Farm 1	0.9677	0.9009	0.9936
Typical Farm 2	0.8273	0.7696	0.9009
Typical Farm 3	0.8796	0.8098	0.9490
Typical Farm 4	0.5455	0.5455	0.5457
Typical Farm 5	0.9334	0.7770	0.9979
Typical Farm 6	0.5983	0.5394	0.6449
Typical Farm 7	0.7096	0.6649	0.8134
Typical Farm 8	0.7327	0.7184	0.7348
Typical Farm 9	0.5791	0.5273	0.6153
Typical Farm 10	0.7553	0.6665	0.8586
Typical Farm 11	0.7263	0.7074	0.7585
Regional Level			
West	0.7007	0.6889	0.7066
Mid-North	0.9430	0.9121	0.9611
Southeast	0.9196	0.8971	0.9301
South Central	0.8349	0.8325	0.8390
Northeast	0.9890	0.9786	0.9933

To evaluate the predictive performance of MONICA, we compared simulated crop yields against observed yields at farm level. Observed crop yields for soybean, maize, cotton and sunflower were taken from datasets described in section 2.2. To test the performance of MONICA, the following evaluation indices were calculated and are shown in Figure 12: root mean square error (RMSE), normalized RMSE (rRMSE) and Willmot´s index of agreement (d). The normalized RMSE ranges between 14.7 for soybean VIII and 36.9 for cotton lint, indicating a reasonable performance of MONICA.

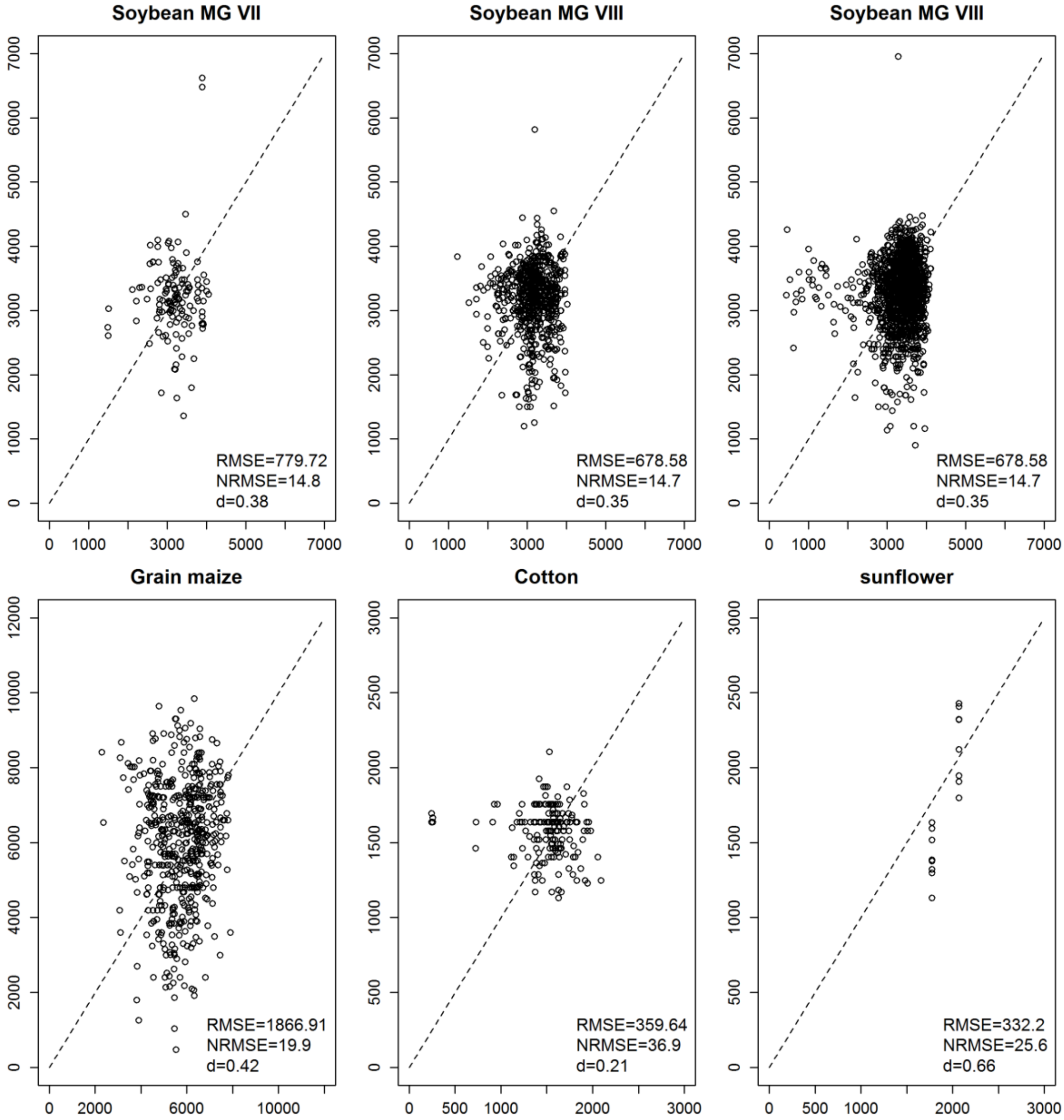


Figure 12. Observed and simulated soybean, maize, cotton, and sunflower yields from different municipalities in Mato Grosso, Brazil

3.2 Simulation experiments

For our impact analysis, we designed two scenarios to (1) simulate innovation diffusion of a new technology (sunflower), (2) estimate potential production of sunflower in MT, and (3) assess the economic impact of sunflower cultivation adoption at farm level. This was done by comparing a baseline scenario [With Sunflower] – which reflects the situation in which, at the beginning of the simulation, only innovators have access to sunflower cultivation (but may decide not to take it) – with a counterfactual scenario [Without

Sunflower] where no sunflower is made available to model agents. To fully capture the technological diffusion process, we ran MPMAS and MONICA models over a simulation period of 15 years.

3.3 Uncertainty analysis (UA)

Since simulation models are usually subjected to considerable uncertainty associated with model inputs (parameters and exogenous variables), an UA was carried out to verify the robustness of our simulation results. We followed the approach of Troost and Berger (2015) and Berger et al. (2017) and identified 18 uncertainty parameters in our modeling approach. Table A 1 presents a complete list of uncertain parameters, which are grouped into four categories: selling prices, input prices, crop yields, and other model parameters. Local prices and yields in MT are, usually, highly correlated (e.g., prices and yields due to their relationship with climatic conditions and forces of supply and demand; crop prices and input prices due to a common dependence on US dollar exchange rates). To preserve the observed correlations in the sampling procedure, we did not sample yields and prices independently but instead sampled complete price/yield vectors for one year from the complete set of local market prices and yields of all years from the local data observed in MT (data was available from 2012 to 2017).

Local prices were corrected for inflation and market trends. We applied the Sobol' sequence sampling method, a quasi-random sampling that tends to converge faster and generates samples more uniformly (Tarantola et al., 2012). To create an entirely controlled experiment that isolates the scenario effect on each individual agent from any variation in other parameters (Troost and Berger, 2015), our simulations were run over 60 repetitions, and each scenario was simulated using the same Sobol' sequence of parameters. As we show in the appendix, we found that 60 repetitions are enough in our case to make the mean, the 5th and 95th percentile of the simulated sunflower land use over the sequence converge to a stable value (see Figure A 1 in the appendix).

4 Results

4.1 Sunflower innovation diffusion in MT

Figure 13 shows the simulated diffusion curves for sunflower in MT for all 60 repetitions over a 15-year period. The adoption rate is estimated as an accumulation of total adopters (number of farmers) over time. Each curve represents one model repetition (section 3.3), which is characterized by a set of model parameters that influences the farmer's decision-making. As shown in Figure 13, the diffusion curves are grouped into five groups/cases that represent a set of local prices and yields observed for a specific year in MT (section 3.3). The technology diffusion process took approximately five simulation years and reached a maximum adoption rate of 32% at some model repetitions [Group A] and a minimum adoption rate of 12% at other repetitions [Group F].

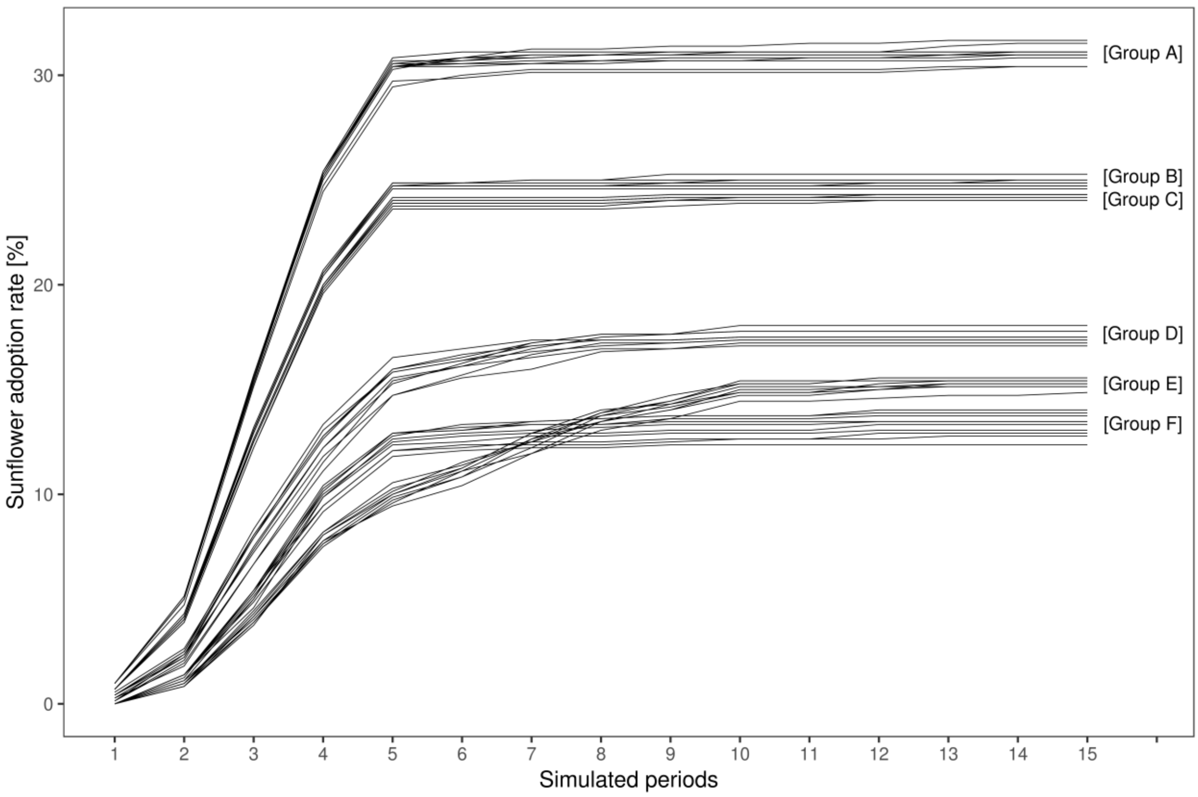
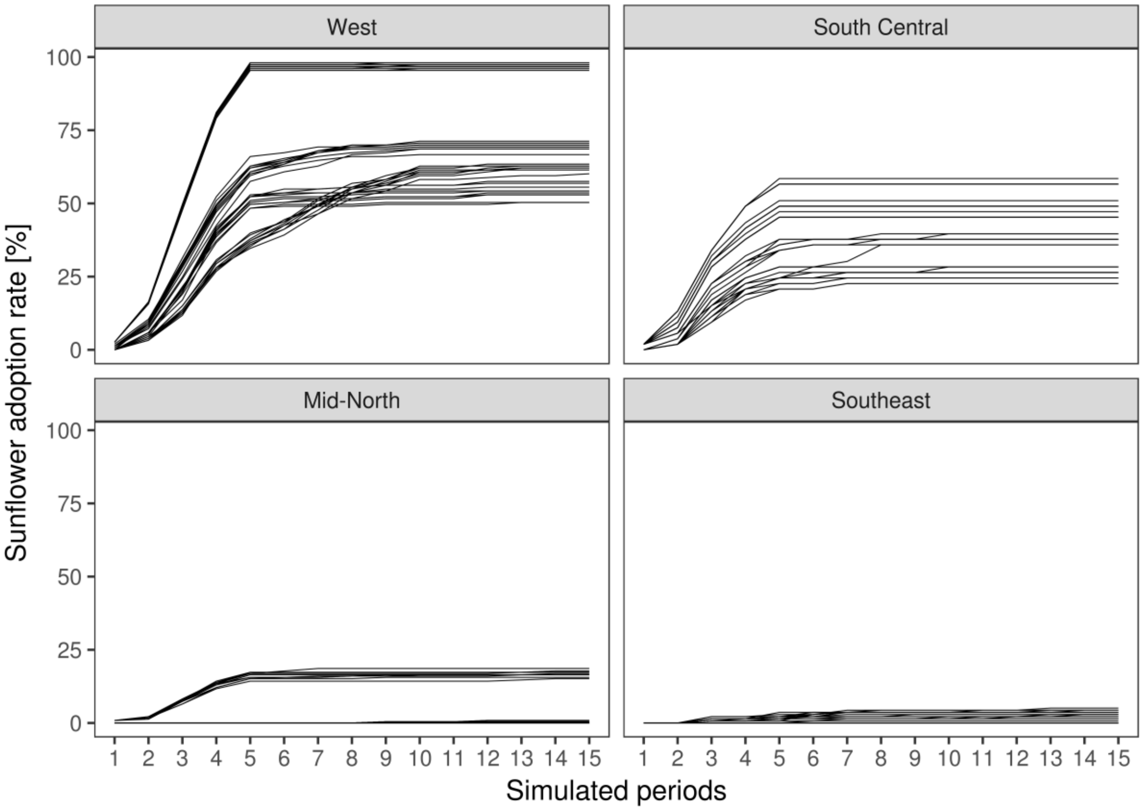


Figure 13. Sunflower innovation diffusion in Mato Grosso over all 60 repetitions

4.2 Sunflower innovation diffusion at regional level

The innovation diffusion of sunflower at the regional level is represented in Figure 14. From the chart, the highest adoption share was achieved in West, whereas Northeast had no adoption. Our simulation shows a negative correlation between sunflower adoption and transportation cost. Since the processing facilities are in West, farmers in other regions face a higher transportation cost, because they have to pay for transporting sunflower to the processing facility. In some repetitions, whole agent population in West adopted sunflower innovation, while other repetitions in West had minimum adoption rate of 50%.

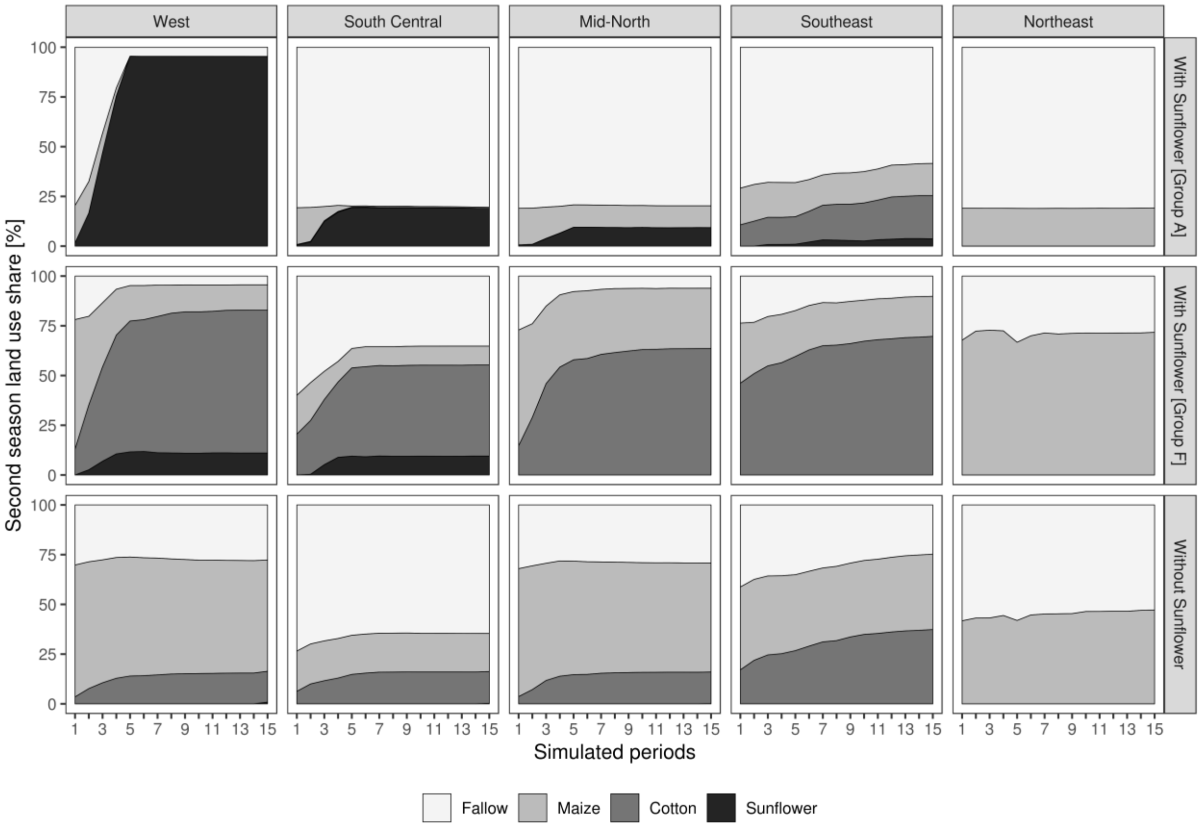


Note: Region Northeast is not shown since it had no adoption

Figure 14. Sunflower innovation diffusion at regional-level over all 60 repetitions

4.3 Land-use trade-offs

Figure 15 disentangles the land-use trade-offs in the second crop season by comparing the land-use allocation between [With Sunflower] and [Without Sunflower] scenarios. Land use share is averaged over all farms and grouped into attractor groups (from A to F). Figure 15 shows groups A and F while other groups are presented at the appendix (Figure A 2). Our simulations show that the main competing crop for sunflower is maize, which had its land-use share reduced in West and South Central (the regions with the most share of sunflower cultivation). There was no reduction in cotton associated with sunflower adoption. Interestingly, regions with higher sunflower adoption also reduced fallow land.



Note: The comparison of other groups is presented in Appendix (Figure A 2).

Figure 15. Land-use allocation at the second cropping season

In cases where prices and yields favored sunflower production [Group A], a substantial intensification of land use was observed together with a decrease in the area of maize. On the other hand, when conditions favored cotton and maize production [Case F], one can observe a slight increase of sunflower adoption and a significant increase of cotton land use.

To further investigate the land-use trade-offs in the second season, we disaggregated the simulated land-use over all sowing dates. Figure 16 shows the land-use difference between [With Sunflower] and [Without Sunflower] scenarios over all repetitions and years (upscaled for Mato Grosso). The highest adoption of sunflower was recorded in 15-Mar, when the maize sowing window is already over. Similarly, the most significant reduction in maize land use was also recorded on the latest sowing dates (20-Feb and 06-Mar), when there is a competition for land use with sunflower. Differences in yields due to changes in precipitation can explain the more substantial reduction of maize land use at 20-Feb and 06-Mar (since maize yields are considerably lower in March in comparison to January/February while sunflower is still profitable in mid-March). Moreover, no significant change in cotton land use was observed, which can be explained by its high economic returns (in comparison to maize and sunflower).

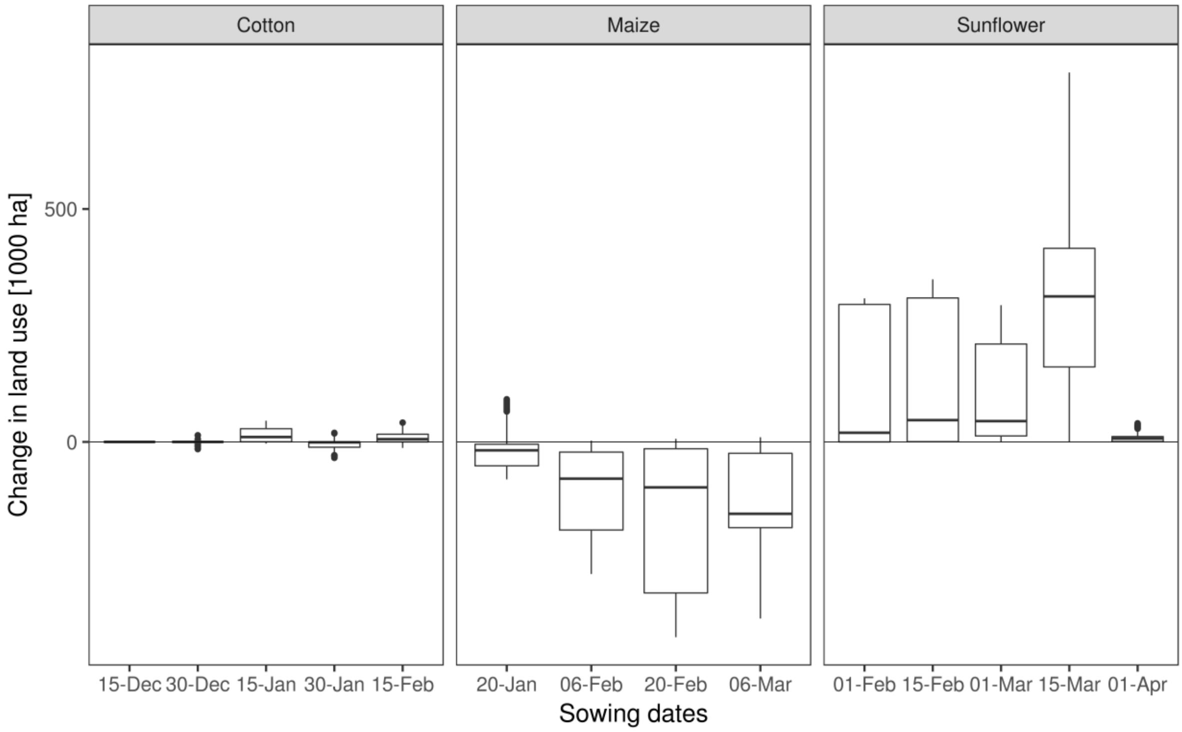


Figure 16. Simulated land-use of cotton, maize, and sunflower upscaled to Mato Grosso using IBGE sampling weights for land use

4.4 Potential production of sunflower in MT

To simulate the potential sunflower production in MT, we allowed farm agents to produce any amount of sunflower that would maximize their expected gross margin, independent of processing capacity. The dashed line in Figure 17 depicts the current processing capacity (approximately 300,000 tons per year), and the solid lines represent the potential sunflower production simulated for MT over a 15-year horizon and all model runs. A substantial variation can be observed over the years and repetitions. For instance, variation from model repetitions can be explained by different agent’s expectation of prices and yields (which are defined by a complete set of local prices and yields observed for a specific year in MT) while different climatic conditions explain variation from years.

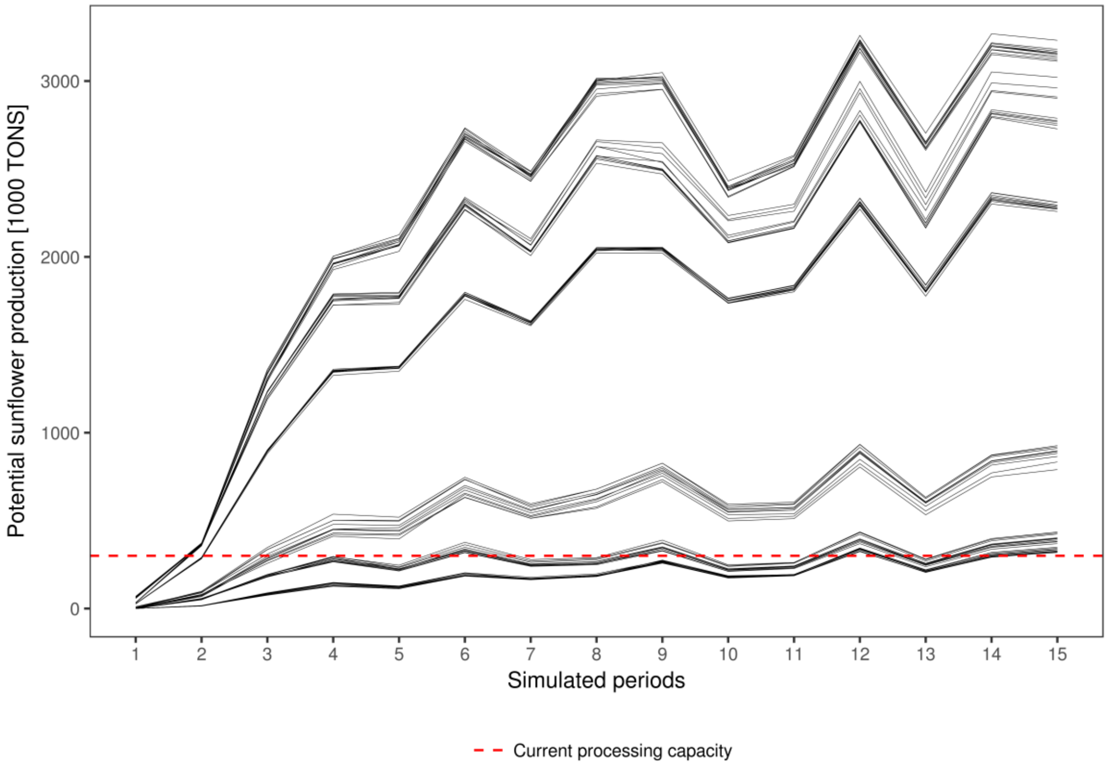
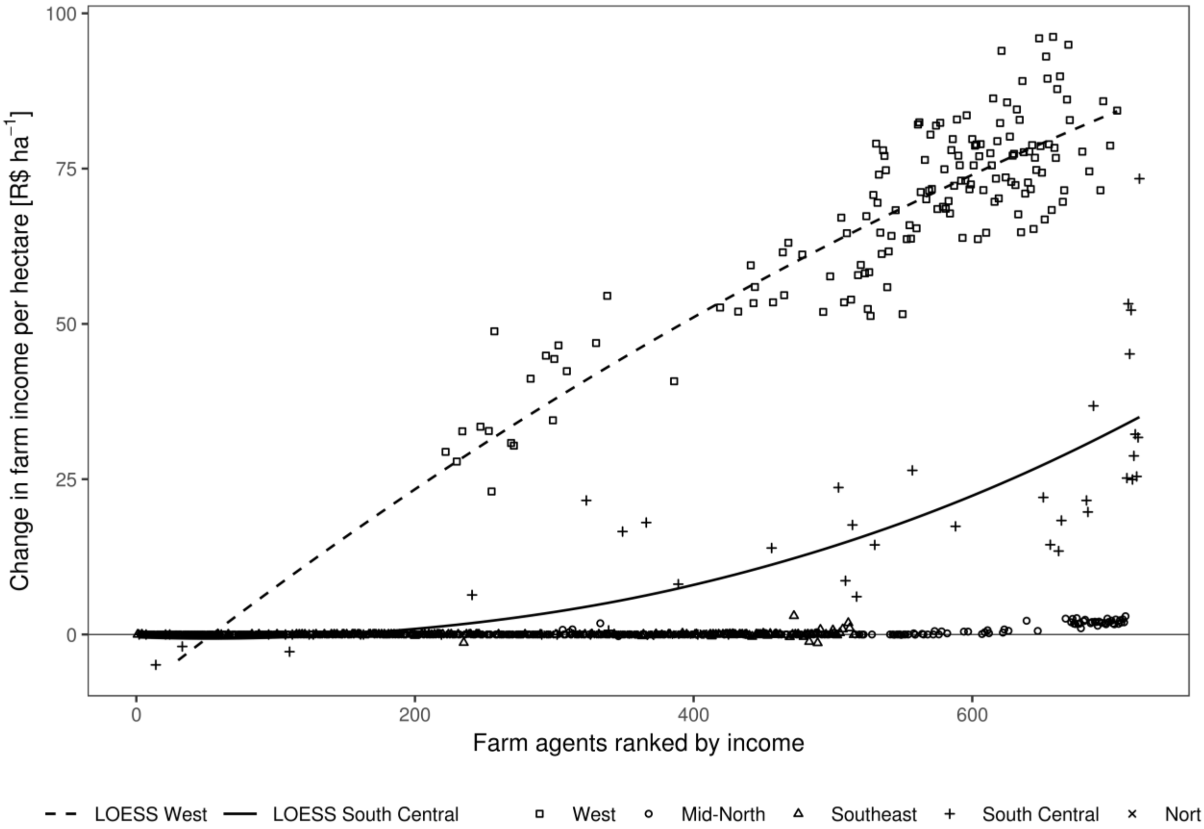


Figure 17. Potential production of sunflower in Mato Grosso over all 60 repetitions (upscaled using IBGE sampling weights for land use)

4.5 Impact of sunflower adoption on farm income

To investigate the impact of sunflower adoption on farm-level income, we compared farm income between both scenarios (with and without sunflower). Figure 18 ranks individual agents by their average income per hectare in the counterfactual scenario [Without Sunflower] over all repetitions and years. Our simulation indicates a positive impact of sunflower on farm income. Moreover, a closer look at regional level reveals that its impact is stronger in the regions West and South Central due to their proximity to the processing facility.



Note: Individual agent incomes were averaged over all repetitions and years and then ranked by income in the counterfactual scenario [Without Sunflower]. LOESS span (amount of smoothing) = 2.

Figure 18. Income change in the baseline [With Sunflower] compared to counterfactual scenario [Without Sunflower]

4.6 Economic impact of sunflower adoption at regional level

Table 15 shows the impact of sunflower diffusion at MT and regional level, considering all 60 repetitions and 15 years that were simulated for both scenarios (e.g., pairwise comparisons of farm income for each agent). The impact of sunflower adoption is measured by relative changes in income and income variance. We computed the average and variance of income for each agent in each model repetition and, to control for positive trends in income, the variance of income was calculated from deviations around a three-year moving average rather than plain average. We found a high incidence of “economic opportunity”, where the introduction of sunflower increased average income with higher variance. In approximately 15% of cases, sunflower adopters reported higher average income with lower variance (“ideal outcome”).

Table 15. Economic outcome after sunflower adoption

Indicator	Mato Grosso		West		South Central		Mid-North		Southeast	
	All agents	**Only adopters**	**All agents**	**Only adopters**	**All agents**	**Only adopters**	**All agents**	**Only adopters**	**All agents**	**Only adopters**
"Ideal outcome"										
Incidence of higher average income with lower variance (%)	3%	15%	15%	18%	0%	1%	0%	1%	0%	8%
"Stabilization"										
Incidence of identical average income with lower variance (%)	1%	2%	2%	2%	0%	0%	1%	1%	2%	5%
"Economic opportunity"										
Incidence of higher average income together with higher variance (%)	17%	80%	62%	77%	38%	94%	3%	90%	0%	45%
"Without uptake"										
Incidence of identical average income and variance (%)	77%	0%	19%	0%	58%	0%	95%	0%	95%	0%
"Costly stabilization"										
Incidence of lower average income with lower variance (%)	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%
"Maladaptation"										
Incidence of equal or lower income with higher variance plus incidence of lower income with equal variance (%)	2%	4%	3%	3%	3%	5%	1%	7%	3%	39%

Note: "Incidence of higher average income with lower variance" is computed as follows: for all agents in all repetitions, we counted the number of cases where an individual agent increased its average income after the introduction of sunflower [With Sunflower] over 15 years against the counterfactual scenario [Without Sunflower] while at the same time decreasing the variance of income around the three-year moving average. We then related the number of these cases to the total number of all simulated cases. All other incidences were computed analogously. Region Northeast is not shown since it had no adoption.

5 Discussion

This study followed an integrated modeling approach to simulate the diffusion of sunflower in MT. Our simulation results indicate that its diffusion process took approximately five years and reached about one-third of the agent population, which suggest that sunflower could be a potential alternative to current farming systems in MT.

Furthermore, our analysis at the regional level shows that sunflower adoption is strongly constrained by the distance between farm gate and processing facility. In other words, building processing facilities in other regions might be a necessary condition for sunflower diffusion in MT.

On the other hand, the most interesting finding was that farm proximity to a processing facility is not a sufficient condition to sunflower diffusion. A closer look at the agent's decision-making reveals that sunflower land use is strongly associated with the agent's expectation of prices and yields. This result underlines the importance of considering the farmer's economic incentives and decision-making in integrated assessment studies of technology diffusion.

Our impact assessment reveals that the adoption of sunflower leads to land-use intensification. A possible explanation for this result is the extension of sowing window in the second season created by sunflower adoption. Since sunflower is more tolerant to water stress than maize, agents managed to cultivate more crops in March after sunflower adoption (a period in which maize yields are significantly affected by water deficit).

Our results, as shown in Figure 17 indicate that further improvements in processing capacity are needed in MT to achieve potential sunflower production since most simulated cases were above its current processing capacity.

We also captured the economic trade-offs in double-crop production systems in MT. In terms of sunflower cropland, we found no evidence of competition with cotton land use. On the other hand, we found strong evidence of competition with maize. Taken together, these findings suggest that sunflower can be a potential alternative for years with low maize prices since cotton is a complex system and requires high amounts of capital and expertise.

The results of our simulations suggest that sunflower contributed to increased farm income. In about 20% of all cases (720 agents * 60 repetitions * 15 years) sunflower was adopted by model agents. In many of these cases, adopters experienced an increase in farm income (although in most of the cases an increase in income variance was also observed). In contrast, we also found a low incidence of “maladaptation” (better off not adopting sunflower cultivation due to equal or lower income with higher or equal variance) and “costly stabilization” (lower average income with lower variance), which suggest that the diffusion of sunflower generally benefited farmers.

6 Conclusion

To the best of our knowledge, this is the first study in MT to estimate the potential sunflower production and to assess its impact at the farm level. This study has shown that there is a substantial potential for sunflower cultivation in MT, which could meet an increase in demand related to the implementation of high-quality sunflower protein ingredients.

Our IA approach also allowed us to identify bottlenecks for sunflower diffusion. The results of this study show that the distance from the farm gate to the processing facility had a significant impact on sunflower adoption. Another relevant finding was that expected crop prices and yields play a crucial role in agents’ decision-making and, consequently, on sunflower land use. This finding suggests that an innovator interested in expanding sunflower production in MT should consider the implementation of contractual and price mechanisms able to raise the comparative advantage of sunflower in relation to maize.

Furthermore, our findings suggest that sunflower can be an alternative agricultural practice because it can increase farm income and land use intensification. Thus, since sunflower increases the sowing window in the farm, it can be a potential strategy for climate change adaptation, giving more flexibility to field operations and reducing risk to water stress.

7 Appendix

Table A 1. Parameter variation in the Sobol' sample

Variable	Distribution or sampling method	Min	Max
Soybean price	RS	0.96	1.15
Maize price	RS	0.85	1.19
Cotton price	RS	0.91	1.04
Sunflower price	RS	0.98	1.05
Fertilizers price	RS	0.99	1.07
Herbicides price	RS	0.92	1.04
Fungicides price	RS	0.75	1.09
Insecticides price	RS	0.99	1.05
Seed price	RS	0.95	1.17
Soybean yield	RS	0.97	1.03
Maize yield	RS	0.91	1.13
Cotton yield	RS	0.94	1.05
Sunflower yield	RS	0.96	1.09
Initial liquidity	Triangle	0.92	1.08
Self-consumption	Triangle	0.92	1.08
Labor requirement (driver)	Triangle	0.84	1.16
Labor requirement (field operations)	Triangle	0.84	1.16
Overlap parameter	Uniform	0.70	0.90

Note: "RS" means randomly sampled from vector of local market prices and yields. Theta from triangle distributions as well as modus from RS variables equal to unity.

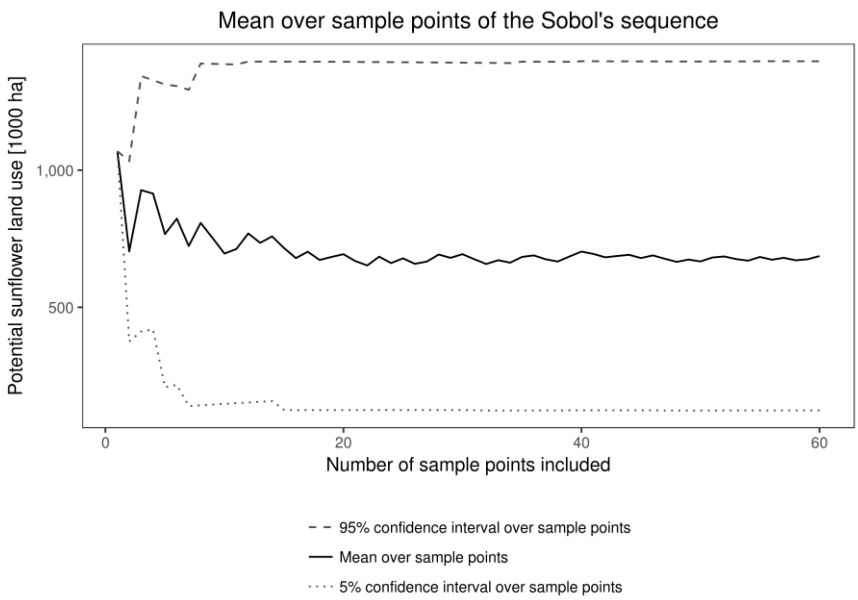


Figure A 1. Convergence of potential sunflower land-use over the Sobol' sequence

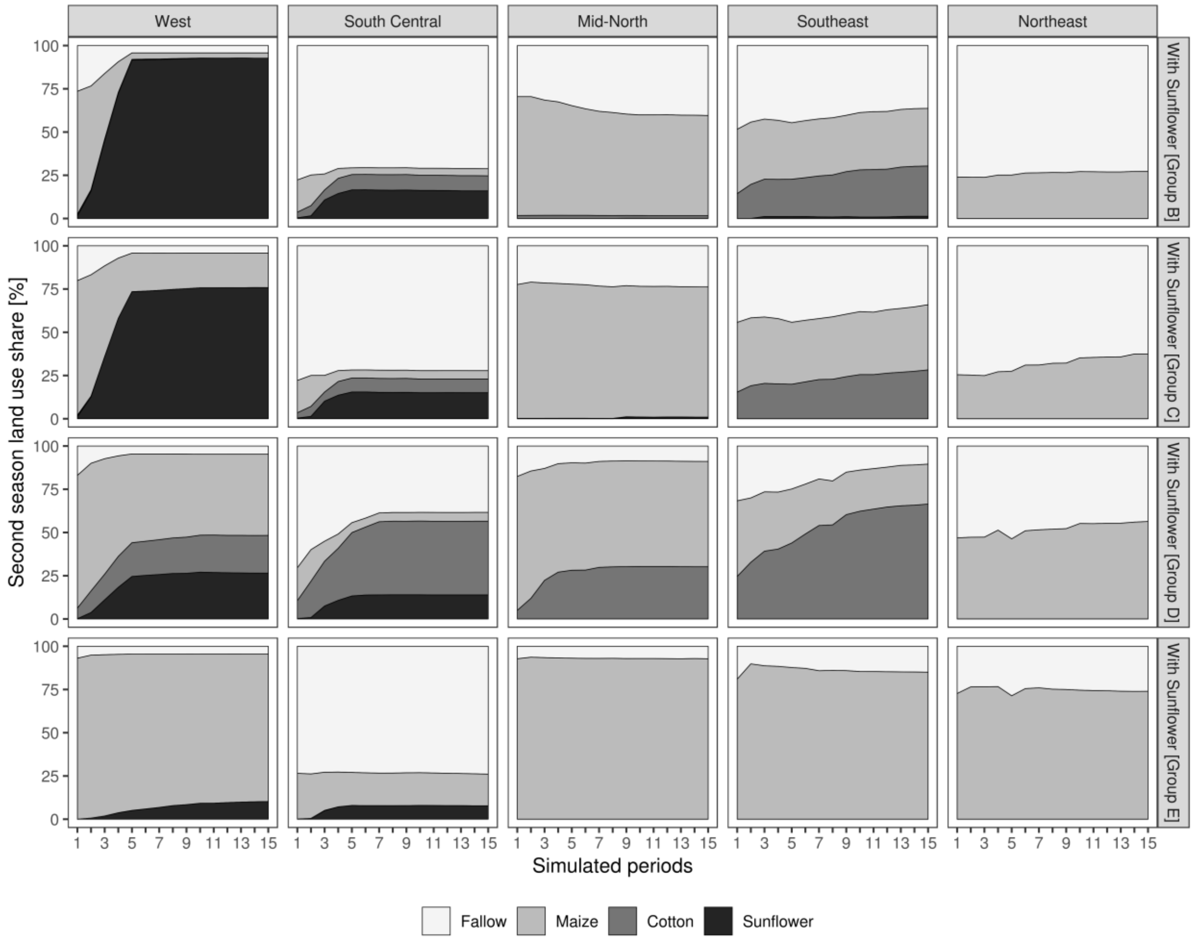


Figure A 2. Land-use allocation at the second cropping season for groups B, C, D and E.

CONCLUSION

This study performed a socio-economic analysis of sunflower agri-food chains in Brazil in view of the potential implementation of food innovations related to plant protein ingredients for human consumption. To this end, a combination of qualitative and quantitative methodological approaches was applied, which enabled the identification of relevant aspects, especially at the farming level, to be considered before a possible implementation of food innovations related to high-quality plant protein ingredients in Brazil.

Three sections were developed to analyze this case. Section 1 described and analyzed the dynamics of operation of existing sunflower agri-food chains in three areas of Brazil comprising the states of Mato Grosso (MT), Goiás and Minas Gerais (GO/MG), and Rio Grande do Sul (RS). Section 2, in turn, described and analyzed the process of establishment of the principal sunflower agri-food chain in Brazil, located in MT, and result of a collective endeavor conducted by farmers. Finally, Section 3 investigated the potential for sunflower expansion in MT taking into consideration biological, socio-economic, and technological aspects of double cropping systems prevailing in grain-producing regions of MT.

Section 1 indicated an operational environment of high transaction costs in the sunflower agri-food chains in Brazil. The high transaction costs were related to chain agents' uncertainties, which, in turn, emerge from a restricted market structure characterized by a low number of sunflower buyers, and an unstable number of sunflower suppliers. Nevertheless, the low level of asset specificity for farmers coupled with the land use competition with well-established crops lead to low exit costs for farmers, which generate interdependencies between farmers and the processing company. In this context, the power relations between these agents are balanced in such a way that the potentially high short-term market power of the buyer reduces due to the long-term dependence on its suppliers. This scenario has a direct influence on the dynamics of operation identified in the sunflower agri-food chains in Brazil, characterized by the "crop promotion" mechanism. In this governance arrangement, the economic transactions are ruled by formal and relational governance structures, and made possible through knowledge diffusion, under the coordination of a processing company. Thus, formal contracts, social networks based on trust, and knowledge diffusion schemes constitute the governance arrangement implemented to provide the necessary conditions for the operation of the sunflower agri-food chains. Nevertheless, this governance arrangement has not been sufficient to ensure the sustainable long-term operation of these chains and to overcome the typical limitations of non-established crops, such as restricted market structure, land use competition with well-established crops (e.g., maize and soybean), and technological limitations (e.g., regarding plant breeding, and control of pests and diseases). Therefore, contracts, social networks, and knowledge diffusion only provide the initial or short-term stimulus to the agents from the farming segment supplying sunflower to a processing company but cannot provide stable framework conditions for a continuous and stable supply of sunflower in general. Depending on specific regional characteristics, additional factors play a role.

In this line, despite the challenges for the long-term operation of the sunflower agri-food chains in Brazil, Section 1 showed that the sunflower chain located in MT stood out regarding the operational stability. This agri-food chain, collectively organized by farmers, is the most recent but the largest one, and the only one focused on the market segment of edible sunflower oil. Thus, this farmer-led chain showed that a close intertwining of farmers and the processing company can reduce the risk of feedstock shortage as well as transaction costs (e.g., costs concerning the searching and supporting of suppliers), besides providing a stronger stimulus to knowledge diffusion due to a more consistent trustful relational environment.

Section 2 indicated that the process of establishment of the farmer-led sunflower agri-food chain in MT has been a complex social-economic endeavor stemming from a set of connected driving forces composed of entrepreneurial skills, social network, resource availability, and crop suitability. The component of entrepreneurial skills led the group confronting limitations (e.g., the unfavorable geographical location), adopting a strategic decision-making approach (e.g., the definition of the chain focus and the risk-mitigating strategies), besides supporting the agri-food chain planning, implementation, and growth. The social network component was revealed by the role of trust and reputation in shaping the economic actions in the agri-food chain. In this regard, the composition of the organizing group based on mutual trust and common goals was a key factor that assured members' commitment and cohesion over time, fundamental for the agri-food chain implementation and growth. The component of resource availability was evidenced by the internal-driven approach of the chain endeavor, without any direct participation of intermediary supporting organizations. Thus, the fact that group members being large-scale farmers with other income sources than sunflower was fundamental for the group to bear the costs and risks associated with the implementation and operation of a new agri-food chain. The component of crop suitability, in turn, derived from a set of aspects that have guaranteed at least a minimum level of farmers' willingness to adopt sunflower over time. The following aspects were identified: (1) the crop dovetail with the local farm production system, not affecting farmers' main income source, (2) the low level of specific investments due to the use of available productive resources for soybean and maize, (3) the previous sunflower cropping experience of a reliable farmer with high leadership ability, and (4) the implementation of knowledge diffusion schemes. Thus, these four components enabled the horizontal cooperation and the downstream collective vertical coordination, allowing farmers to independently identify and develop the opportunity related to the sunflower agri-food chain, overcoming barriers associated to the initial development stage of the sunflower sector in Brazil, besides lessening risks of transactions failure, and favoring the growth of the company.

Furthermore, Section 2 also suggested the existence of a supportive institutional environment for the collective establishment of new sunflower agri-food chains in MT among soybean farmers. Besides the availability of arable land and productive resources suitable for introducing sunflower as a second season crop, soybean farmers in MT share a similar cultural background of pioneering and collective actions, which lessens transaction costs and individual financial requirement, favoring horizontal cooperation and collective investment. In this regard, the current farmer-led sunflower chain could act as a role model for soybean farmers from other agricultural regions in MT. Nevertheless, the case study also highlighted the complexity for a lasting collective establishment of an agri-food chain, especially if led by outside actors (e.g., intermediary organizations). This complexity arises from the difficulty to foster the driving forces (especially the components of entrepreneurial skills, and social network) underlying the successful establishment process of this agri-food chain. Moreover, Section 2 indicated that, despite its successful development, the farmer-led chain faces challenges, mainly related to the instability of the sunflower producing area over the years, which is associated with the status of a non-established crop that sunflower still has in Brazil.

Section 3 indicated the existence of a potential for the expansion of the sunflower production in MT. Nevertheless, the regional level analysis highlighted that this potential is constrained by the distance between the producing areas and the processing facilities, currently installed in the western region in the municipality of Campo Novo do Parecis. Thus, because of transportation costs, the simulated sunflower land use was concentrated in the regions West and South Central, which are closer to the sunflower processing-area. Therefore, the establishment of new processing facilities in other regions could increase the adoption of sunflower in MT.

Nevertheless, the simulations also showed that the farm proximity to a processing facility is not a sufficient condition to sunflower diffusion. This is due to land use competition with maize (also observed in Sections 1 and 2), confirmed in the assessment of the land use trade-offs in the second growing season. The simulations revealed that sunflower land use is strongly associated with agents' expectations regarding prices and yields of sunflower and maize. Thus, high levels of sunflower adoption could be associated with higher sunflower yields and prices, and lower maize prices and yields, while higher maize prices and yields led to a lower level of sunflower adoption in MT. The agents' expectations on prices and yields coupled with the different climate conditions captured by the simulations were the main reasons for the substantial variation observed in the simulation of the potential production of sunflower in MT. Thus, this finding confirms the challenge of ensuring the stability of sunflower supply over the years, especially in years of soaring maize prices, observed in Sections 1 and 2.

On the other hand, the analysis of the simulated sunflower land use allocation per sowing date showed that the highest adoption of sunflower was recorded after the sowing window of maize, suggesting a complementary effect between maize and sunflower. In other words, the farmers should not replace maize by sunflower, but adding sunflower into the double cropping system, leading to land use intensification, as represented by the reduction of fallow land verified in the regions with higher sunflower adoption.

Furthermore, Section 3 indicated that the achievement of the potential production of sunflower would require further increases on processing capacity in MT. Nevertheless, findings from Sections 1 and 2 showed that the existing sunflower processing companies in Brazil have operated below their processing capacity due to the land use competition with well-established crops related to the limitations of sunflower as a non-established crop in the country.

General conclusion

The analyses performed in Sections 1, 2, and 3 to the sunflower case study in Brazil indicated relevant aspects to be considered by decision makers (innovators) from the food industry interested in implementing food innovations related to non-established crops.

(1) The scarcity of feedstock suppliers requires the adoption of contractual and relational governance structures coupled with the provision of technical assistance at the farming level.

(2) Farmers with recognized professional and social reputation and leadership ability play an important role in influencing other farmers in the process of diffusion of a non-established crop, and for the agri-food chain establishment

(3) The suitability of the crop for the agricultural system prevailing in the region is essential for ensuring a minimum level of farmers' willingness to adopt a non-established crop. In this regard, particular attention should be given to the land use competition with well-established crops, since it can prevent the achievement of the potential for the crop diffusion, and the agri-food chain establishment.

Recommendations

The introduction of high-quality sunflower food protein ingredients could benefit the sunflower sector in Brazil, especially in MT, which possesses the most favorable conditions for the expansion of the sunflower production. If higher overall profitability at the processing level leads to higher sunflowers prices, the comparative advantage of sunflower with competing crops will raise, contributing to the growth and stability of sunflower production. Nevertheless, some aspects highlighted in the analyses of Sections 1, 2, and 3, and summarized in a short analysis of the sunflower sector in MT (Table 16) suggest that food innovators should consider the following recommendations before a possible implementation of high-quality sunflower protein ingredients in MT.

Table 16. Short analysis of the sunflower sector in Mato Grosso

Internal factors	
Positive	**Negative**
1. Large-scale grain producers. 2. Availability of arable land and widespread double-cropping system. 3. Experience in collective sunflower agri-food chain establishment.	1. High influence of maize prices on farmers' decision on sunflower land use allocation. 2. Short-term view of farmers. 3. Low level of sunflower cropping knowledge outside the western region.
External factors	
Positive	**Negative**
1. Potential for sunflower expansion in double-cropping systems adopted by farmers. 2. Favorable institutional environment for the development of agri-food chains. 3. Market segment of high-quality plant protein ingredients for human consumption. 4. Potential demand for sunflower oil.	1. Lower technological level of sunflower regarding plant breeding and control of pests and diseases in comparison with the main competing crop (maize). 2. Long distances to the main food industry center, and to the ports. 3. High energy costs.

(1) The crop promotion mechanism should continue to be employed while sunflower remains as a non-established crop. It means the use of contractual and relational governance structures coupled with the provision of technical assistance for sunflower growers.
(2) Efforts should be made by the sunflower chain stakeholders (mainly the leader of the innovation implementation) to foster the research concerning plant breeding, and disease and pest control for sunflower in Brazil. These actions would increase sunflower yields. Consequently, more farmers would be attracted to the business of sunflower due to higher profitability, minimizing the adverse effects of land use competition for the sunflower supply stability.
(3) The adoption of supply chain management (SCM) strategies could generate gains related to the feedstock supply stability in sunflower agri-food chains. These strategies should focus on providing to the chain actors (especially to sunflower growers) a long-term perspective, which could reduce uncertainties and transaction costs.
(4) The long distances to the main food industry center and the ports, as well as the high energy costs in Brazil, require further investment analyses before the investment in the expansion of sunflower processing capacity. These analyses should evaluate the conditions under which the implementation of sunflower food innovations and a possible establishment of new sunflower agri-food chains would be profitable for the agents across the different segments of the agri-food chain. Furthermore, investments analyses would support the decision about the location of possible new sunflower processing facilities.
(5) If the risk of feedstock shortage is considered too high, and the expected profits from the operation in the plant-protein market segment appear sufficiently high, decision makers should consider the adoption of long-term contracts (ideally with a price system that seeks to guarantee better profitability for sunflower in comparison with competing crops), formal partnerships with a group of large-scale farmers, or even vertical integration. Nevertheless, the total control of feedstock provision applies only if the asset specificities for the high-quality sunflower proteins are considerably high and become a dominant entrance and exit barrier that increases substantially the transaction costs, hazards, and risks of transaction failure. Although vertical integration is not often observed in annual oilseed chains

in the country, the incremental revenue related to high-quality plant protein could change this scenario for sunflower agri-food chains.

(6) In the case of collective agri-food chain development, particular attention should be given to the group of individuals involved in the chain endeavor. The cohesion and commitment of the individuals over time depends on a set of aspects like mutual trust, professional and social reputation, and previous collaborative experiences as well as technical and entrepreneurial skills. Thus, these aspects should underlie the definition of the group of individuals to be part of a collective agri-food chain endeavor.

Future research directions

The analysis of the establishment process of the farmer-led sunflower agri-food chain in Mato Grosso revealed the crucial role of key individuals in the development of an agri-food chain. Thus, a small number of individuals are responsible for generating socio-economic benefits at a regional level concerning job and income generation related to the agri-food chain establishment. Therefore, further research is needed to identify key individuals in other agri-food chain endeavors across the country and investigating if they are characterized by specific socio-demographic and socio-psychological characteristics. Such analysis could support processing companies and intermediary organizations in identifying and selecting key individuals to take part of agri-food chain endeavors. Additionally, econometric approaches to analyze the crop adoption (e.g., logit or probit models) and land use competition patters could provide valuable information regarding the socio-economic profile of crop adopters, which could also support the implementation of new sunflower agri-food chains.

Regarding the bio-economic model-based approach, further research should consider the limited sunflower processing capacity by implementing a model extension that represents the interactions between processing facilities and farmers. Another possible area of future research would be to investigate sunflower adoption under climate change and to analyze "maladaptation" cases for effective policy intervention.

Also, the assessment of the drivers of land use competition in the presence of sunflower production should be considered in future research using econometric analyses once longitudinal and time series data from sunflower cultivation in double-cropping systems are available. Among several drivers, the assessment of the role of price, price risk, and yield risk on land use competition could present valuable information to support the setting of contractual items in sunflower agri-food chains.

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2015 – present: Doctoral candidate at the Faculty of Agricultural Sciences, University of Hohenhein, Stuttgart, Germany

2009 – 2011: Master of Science in Applied Economics, Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil.

2004 – 2009: Bachelor of Science Degree in Agribusiness Management, Federal University of Viçosa (UFV), Viçosa, Minas Gerais, Brazil.

2008: Visiting scholar at The Ohio State University, Columbus, Ohio, USA. (Fall quarter).

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PUBLICATIONS

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Sousa, L. O. d., Dias Paes Ferreira, M., Mergenthaler, M., 2018. Agri-food chain establishment as a means to increase sustainability in food systems: Lessons from sunflower in Brazil. *Sustainability.* 10, 2215. https://doi.org/10.3390/su10072215

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Participation in Scientific Event

November 8-10, 2017 Castelldefels, Spain 7th EAAE PhD Workshop

Oral presentation: An entrepreneurial process of agri-food chain establishment: cases of sunflower agri-food chains in Brazil

August 28 – September 1 in Parma, Italy XV EAAE Congress 2017

Poster presentation: The emergence process of sunflower agri-food chains in Brazil

February 13-17, 2017 in Innsbruck-Igls, Austria 11th International European Forum (Igls-Forum) (161st EAAE Seminar) on System Dynamics and Innovation in Food Networks

Oral presentation: The Role of Trust, Knowledge Diffusion and Contracts in Sunflower Production Chains in Brazil

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AUTHOR'S DECLARATION

Affidavit

pursuant to Sec. 8(2) of the University of Hohenheim's doctoral degree regulations for Dr.sc.agr.

1. I hereby declare that I independently completed the doctoral thesis submitted on the topic "**Socio-economic evaluation of sunflower agri-food chains in Brazil in view of the potential implementation of innovative plant protein ingredients for human consumption"**

2. I only used the sources and aids documented and only made use of permissible assistance by third parties. In particular, I properly documented any contents which I used - either by directly quoting or paraphrasing - from other works.

3. I did not accept any assistance from a commercial doctoral agency or consulting firm.

4. I am aware of the meaning of this affidavit and the criminal penalties of an incorrect or incomplete affidavit.

I hereby confirm the correctness of the above declaration. I hereby affirm in lieu of oath that I have, to the best of my knowledge, declared nothing but the truth and have not omitted any information.

Lucas Oliveira de Sousa
Stuttgart, 2018.