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Perception of grain farmers in the Brazilian Cerrado region regarding the adoption or nonadoption of bioinputs

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Summary

The adoption and expansion of bioinputs in rural areas seems to be one way to increase the number of ecological crops and production based on three pillars of sustainability: the environment, society and the economy. Thus, to understand the motivations and barriers that lead grain farmers in the Brazilian Cerrado region to adopt (or not) and expand (or not) the use of bioinputs, this study collected data from 122 farmers who answered closed-ended questions on a 5-point *Likert* scale related to the producer profile, limitations and motivations regarding the bioinput topic. After the descriptive statistical analysis, graphs and binomial logistic regression (Logit), the main conclusions were that the nonfamily farmer is the main consumer of bioinputs under the studied conditions and that rural technical assistance, when efficient, also promotes the adoption and increased use of biological products.

Keywords: Regenerative Agriculture, Bioeconomy, Motivations, Bioinputs

1. INTRODUCTION

The search for more sustainable agriculture that is more resilient to environmental dilemmas has motivated the governments of developed and developing countries, as well as companies belonging to the food production chain, to invest in new technologies and management techniques that protect the environment. (HARDOIM; MARTINS; MARTINS, 2023).

In this context, regenerative agriculture is a production model that aims to improve soil quality, promote biodiversity, capture carbon, preserve the water cycle, promote animal and human welfare, and promote profitable agricultural production (MPANGA et al., 2021; DAY; CRAMER, 2022).

Among the technological tools for regenerative agricultural production is bioinput*,* defined by the Brazilian government through the National Bioinput Program (Decree No. 10,375 of 2020 and amended by Decree No. *process or technology of plant, animal or microbial origin, intended for use in the production, storage and processing of agricultural products, aquatic production systems or planted forests, which positively affects growth, development and the response mechanism of animals, plants, microorganisms and derived substances and that interact with the products and the physical-chemical and biological* processes” (BRASIL, 2020, 2024).

In practice, the term bioinput is used as a synonym for biofertilizers, biopesticides and inoculants, among other biologically based products, which were initially used in organic or agroecological agriculture but currently play an increasing role in conventional agriculture. An alternative or a complement to fertilizers and phytosanitary products can reduce production costs (VIDAL et al., 2020).

However, the perception of the adoption and use of biological products in the production system is still permeated by barriers and limitations by many rural producers. Identifying the factors that determine such limitations as well as the motivations for the use of this technology is essential for expanding practices in the agricultural environment. Therefore, the present study is guided by three important questions:

a) “What *is the profile of rural grain producers in the Brazilian Cerrado that contributes to the adoption or nonadoption of bioinputs on their properties?*”
b) *“Which source(s) of origin and update are determinant for the producer to know the bioinput technology that impacts the decision-making of the use of technology in the field?*
c) “What *are the barriers or limitations that prevent the adoption or increase in the use of bioinputs by grain producers in the Brazilian Cerrado?*”

The Brazilian Cerrado was chosen as the study site for this work because there has been movement on the part of rural producers in this region to adopt the use of bioinputs on their properties, aimed at the production of large grain crops, especially soybeans.

2. THEORETICAL FRAMEWORK

2.1 Motivations for adopting the use of technology in regenerative agriculture

The motivations that lead rural producers to adopt the use of technologies on their properties are not yet well established. However, researchers such as Ryan & Gross (1943), Kivlin & Fliegel (1967), Adesina & Zinnah (1993), Negatu & Parikh (1999), Rogers (2003), Prager & Posthumus (2010) and Ruzzante, Labarta & Bilton (2021) presented studies that show that the theory of agricultural technology adoption is multidisciplinary and combines elements of three main fields, called paradigms, which highlight the role of different factors in the rates and patterns of adoption of new technologies. Among the factors, three different paradigms can be highlighted: a) that of the diffusion of innovation, in which information is considered a critical parameter that controls the diffusion of an innovation through society; b) that of economic restrictions, in which rural producers aim to maximize utility, using unequally the resources destined for the adoption of technology; and c) the perception of the adopter, which allows for a level of subjectivity by stating that it is the perceived need to innovate and the perceived attributes of innovations that determine adoption behavior on the basis of cultural, contextual and individual factors.

In this context, Ruzzante, Labarta and Bilton (2021), using empirical studies on adoption theories, reported that the education of producers, the size of the household and the property, access to credit, access to rural extension services and membership in organizations and cooperatives are positively correlated with the adoption of agricultural technologies. In addition, O'Donoghue, Minasny & McBratney (2022) emphasize that regenerative technologies have substantial support from the consumer market, the business parts of the food chain and the producers themselves, who hope that regenerative agriculture can be confirmed as a system of agricultural production that increases the quality of the product and the availability of resources on which agriculture depends, such as soil, water, biota, renewable energy and human effort. Another relevant factor that encourages the adoption and expansion of regenerative agriculture technologies is social learning through the exchange of knowledge and the sharing of the effects of technologies (SOTO et al., 2021).

Finally, moving away from conventional agricultural models, which are dependent on chemical inputs, the adoption of sustainable food production systems, which are based on ecological practices and landscape management, is a change of no return. (LEMKE et al., 2024). Thus, scientific innovations aimed at this new model are fundamental in this new scenario. Among these innovations, the adoption of bioinputs has emerged as a sustainable alternative for the ecosystem (GETAHUN, 2020; EJEM et al., 2023). The bioinput market in Brazil is on the rise, driven both by technological advances and by the regulation of sustainable agricultural practices (VALENTE, 2024). According to CropLife Brazil (CLB), in the 2021–22 crop year, soybean was the crop with the highest participation of bioinputs, representing 42% of the total used in Brazil, followed by cotton, sugarcane and corn. In addition, the value of the Brazilian bioinput market increased by approximately 154% in 2021–22 compared with that in the previous crop year (VALENTE, 2024). Therefore, the consumer market for bioinputs is growing. Therefore, it is important to understand the motivations that lead rural producers to adopt or expand the use of bioinputs.

2.2 Limitations/barriers to the adoption of technologies in regenerative agriculture

The adoption or expansion of bioinputs on rural properties, although promising, faces challenges inherent to this type of decision-making by rural producers. Social, financial, situational, technological and operational constraints seem to be the main barriers and limitations for the bioinput market. According to Lima (2023), the low technical and knowledge level of rural producers, in addition to the shortage of specialized technical assistance and the technique of the use of biological products, are the main obstacles encountered by agricultural producers. Another important concern is possible biological insecurity, considering that, given the possibility of production by the rural producer himself, within the property (called *for farm production)* of biological products, this may result in risks to plantations, the environment and human health through the selection of pathogens, requiring regulation to prevent this type of situation. This possible risk is minimized during industrial production, which involves more regulations and inspections.

In addition, there is a lack of notable examples in the business field, and producers adopt the technology to act inductively, using examples from other countries and limiting the expansion of the use of bioinputs (MARQUES, 2022). According to Lemke et al. (2024), regulatory problems, lack of technical knowledge, cost and effectiveness of bioinputs are limitations for the biological products market. For these authors, interest in regenerative practices is related mainly to the expected profitability potential rather than the environmental benefits (LEMKE et al., 2024).

Importantly, barriers and limitations are not mutually exclusive. According to Hurley et al. (2023), the main barriers to the adoption of techniques in regenerative agricultural systems are financial viability, lack of knowledge about the benefits of this practice, lack of models, lack of supporting policies and legislation, lack of experience in environmental programs, infrastructure requirements, and lack of technical assistance, among others. These barriers usually occur concomitantly, discouraging rural producers from knowing, adopting and expanding the use of regenerative tools, such as bioinputs.

Thus, it is possible to observe the diversity of barriers and limitations to the adoption or expansion of the bioinput market, and a multifactorial approach to better understand the desires and needs of these consumer-producers is necessary.

2.3 Means of Disseminating Information and Knowledge

According to Silva et al. (2020), rural communication favors the circulation of information, both within the rural environment with agricultural producers and agents of the agricultural environment and in other sectors of the food production chain not necessarily located in the rural environment, such as agribusinesses based in the urban environment. In this context, Brazil began the process of disseminating information on new technologies through the publication of newsletters, lectures and radio programs. Additionally, according to Silva et al. (2020), when observing the relationship between a rural producer and the technical-scientific information received, it is necessary to get closer to the producer to encourage him to take part in the learning and dissemination of new technologies.

Therefore, as the rural producer is the main decision maker within the property and, in most cases, is the one who interacts with the community, with the suppliers of inputs, among other professionals related to the agricultural sector, it is necessary for all those involved to communicate with each other. effective communication to transmit information in a clear and reliable way, establishing interactions between organizations and producers (JANUÁRIO, 2023).

Thus, given that agricultural production involves several risks and uncertainties, it is necessary for rural producers to have adequate access to information for effective decision-making, including the adoption of new technologies and/or the expansion of the use of these technologies (MTEGA, 2021). In this way, agricultural information is generated by various *stakeholders*, such as, for example, the producers themselves, through experience acquired in the medium and long term, or through agricultural research, which must be presented through easy-to-use communication channels. access, in addition to the use of appropriate and simplified language (MUNYUA; STILWELL, 2013; ISAYA et al., 2018, MTENGA, 2021).

Therefore, understanding rural producers regarding the choices of appropriate communication channels is important for improving access to the dissemination and update knowledge of innovations and new technologies, such as bioinputs.

3. METHODOLOGY

The first stage of the research was based on semistructured and qualitative interviews, with the objective of allowing respondents to express their thoughts on the proposed theme, adoption or nonadoption of the use of bioinputs, as presented by Cerveira et al. (2024). In this stage, six grain farmers in the Rio Verde region, state of Goiás, reported their experiences, motivations and limitations regarding the adoption, or nonadoption, of bioinputs on their properties.

Based on the analysis of the qualitative data obtained in these interviews, a structured questionnaire was prepared for the present study, consisting of a set of closed questions on a 5-level *Likert* scale with the following options: unimportant; unimportant; neither important nor unimportant; important; and very important.

The applied questionnaires contained questions related to the socioeconomic profile of rural producers (age, sex, location, property area, production area, main production, family farming practices), in addition to knowledge about bioinputs, motivations and barrier limitations for the adoption of the technology.

First, the questionnaire was shared *online* among the main groups of rural grain producers in the Brazilian Cerrado region. Owing to the low level of engagement of producers in answering the questionnaire, printed questionnaires were subsequently distributed to rural properties, thus increasing the degree of participation of producers. In total, 122 questionnaires were received, answered and validated.

In the first step, the analysis of the data obtained consisted of descriptive statistics, several graphs and a binomial logistic regression (Logit). Binomial logistic regression is a statistical analysis used to classify records based on the values of the input fields and categorical target field. For this purpose, the logit model calculates the values of the coefficients after providing an experimental dataset with known values of the dependent and independent variables. This statistical method is used to determine which producer characteristic(s) affect the adoption or absence of bioinputs (HAIR et al., 2009). With this same logic, the method also answers which factor(s) significantly affect the motivation or limitation of the use of this technology.

In the second stage, the data obtained from these questionnaires were compared between the groups, i.e., between those who adopted the technology and those who did not, via the Mann–Whitney U test and the chi-square test. The Mann–Whitney test is used for the comparison of two unpaired groups, checking whether they belong to the same population, whereas the chi–square test is a statistical test used to determine whether there is a statistically significant difference between the expected frequency and the observed frequency of categorical data, which leads to the assumption of an association between two qualitative variables. These tools were used to determine whether the source of origin and update the knowledge of bioinput technology contributed to its adoption (HAIR et al., 2009). For both stages, Jamovi software was used.® (THE JAMOVI, 2022) and Stata® (STATACORP, 2023) as instruments for statistical measurements.

4. RESULTS AND DISCUSSION

4.1 Descriptive profile of the rural grain producers who participated in the study

Based on the responses obtained through the questionnaires administered to rural producers, it was possible to establish a profile of the study participants, as shown in Table 1.

Table 1 - Profile of the rural producers who participated in the study

Descriptive Statistics	N	Omitted	Mean	Median	Minimum	Maximum	Shapiro–Wilk W	Shapiro–Wilk p
Age	122	0	47	47	18	82	0.984	0.161
Property area (ha)	121	1	1,812.55	130.00	11.00	30,000.00	0.462	< .001
Production area (ha)	121	1	1,506.42	115.00	3.00	22,000.00	0.478	< .001
Gender (1 Male; 0 Female)	122	0	91%					
Agr. Fam. (1 Não Fam.; 0 Fam.)	122	0	62%					
Product Main (1 Soybean; 0 others)	122	0	91%					
Know bioinputs (1 Yes; 0 No)	122	0	73%					
Applies bioinputs (1 Yes; 0 No)	89	33	60%					

Source: research data

Table 1 shows that the age group of the rural producers who participated in the study ranged from 18-82 years, with a mean of 47 years. The size of the properties ranged from 11—30,000 hectares. In view of this wide area, the median, which is approximately 130 hectares, is considered the best indicator for representing the most common property. In the productive area, it follows the same logic, with a size of 115 hectares being more representative (median). According to the categorical indicators, the main crop of agricultural production is soybean, with 91% of producers admitting this chain as the main crop. The most representative gender of the respondents was male, with 91% of the respondents and 61.5% being self-declared family farmers. This self-declaration of the producer was validated in Brazilian legislation, which correlates one of the legal aspects, that is, the size of the property, to adjust this categorization. the relationship with the size of the property according to the law to be considered a family farmer. Finally, of the 122 respondents, 73%, that is, 89 producers, declared that they knew the bioinput technology and 33 did not. Among the knowledgeable producers, 60% declared that they make use of this technology on their properties, that is, 53 producers. Figure 01 represents such a distribution:

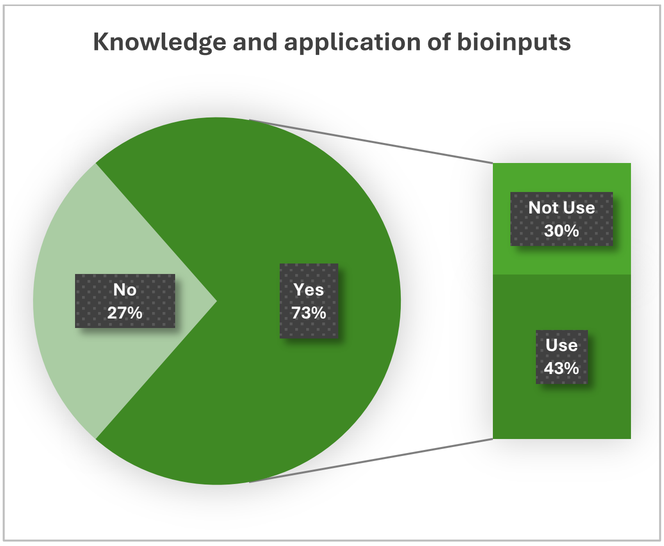

Figure 1 – Percentage of rural producers who know (or do not know) the bioinputs and who apply (or do not apply) the bioinputs in their properties.

According to Figure 2, the states participating in the study were Minas Gerais (54 producers), Goiás (44), Mato Grosso (17), Mato Grosso do Sul (5), Pará and São Paulo, with 1 participant each.

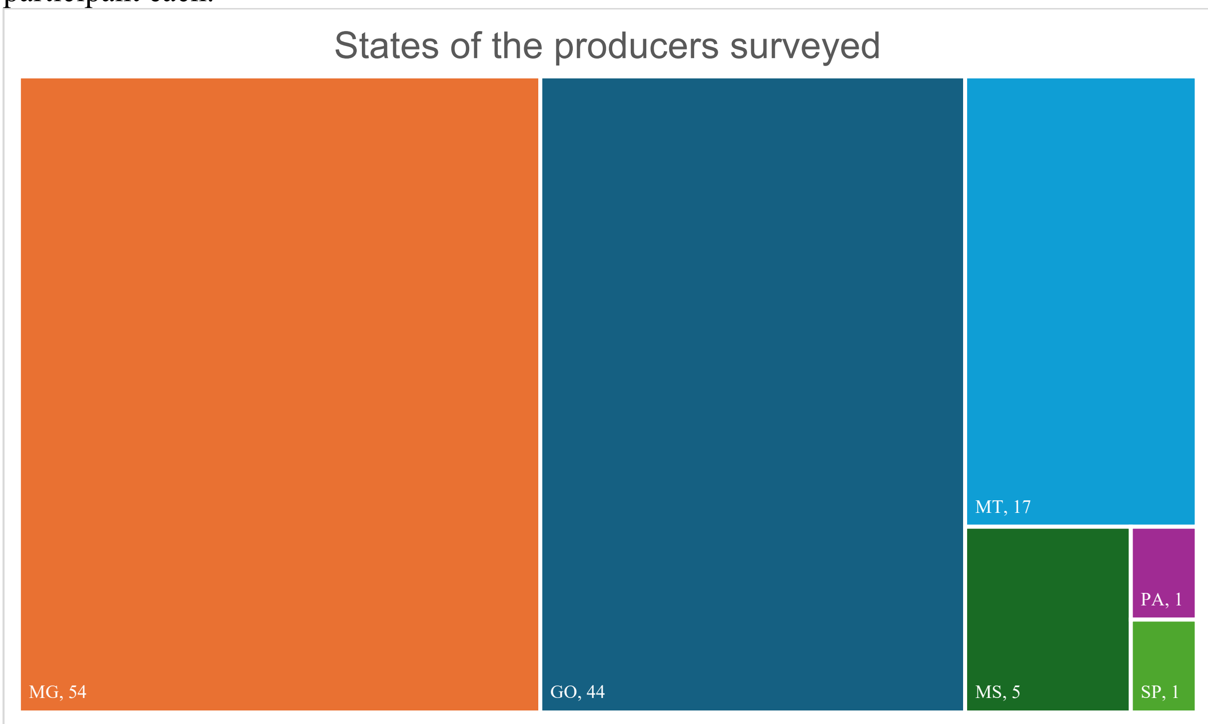

Figure 2 – States of the rural grain producers who participated in the study.

The producers declared that they were knowledgeable about bioinput technology and were presented with a list of statements to verify how much such statements were adherent to their perceptions of the technology. They are as follows: i) I am interested in bioinput technology (Interest_bio); ii) I am willing to grow crops via bioinputs (Willingness_bio); iii) I am motivated to use bioinputs (Motivation_bio); iv) I am able to grow crops via bioinputs (Able_bio); v) I am asked to cultivate them via bioinputs (Requested_bio); vi) I feel pressured to grow crops via bioinputs (Pressed_bio); vii) I believe that I can cultivate prioritizing the use of bioinputs (Prioritize_bio); and viii) I believe that I can grow crops by reducing the use of agrochemicals (Decrease_agroche). Figure 3 represents the results obtained from the average of the responses for each of the statements, considering two subsegments within the segment of knowledgeable producers: a) the subsegment of those who adopt the technology (blue) and b) the subsegment of producers who do not adopt the technology (orange).

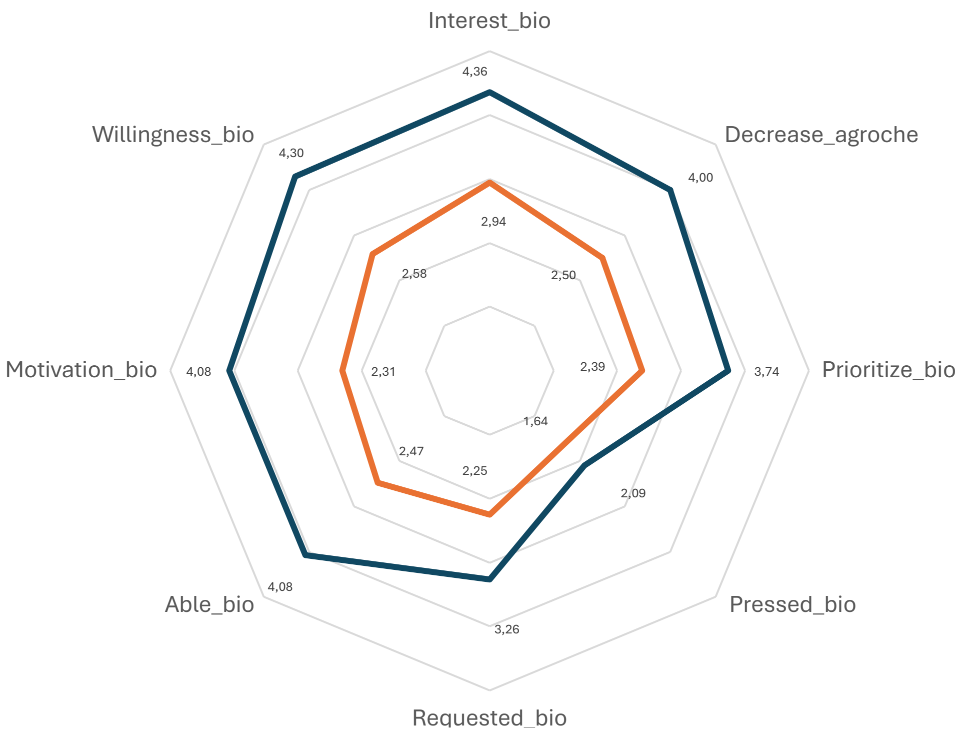

Figure 3 – A scale of importance (0-5) of the factors studied among farmers who know and apply bioinputs (in blue) and those who know and do not apply bioinputs (in orange).

Based on these results, shown in Figure 3, we hypothesize that agreement with the statements regarding the perception factors of bioinputs may have different effects among the segments that use and do not use the technology in question. This may of course be influenced by some of the characteristics of the socioeconomic profile, which will be analyzed in the next part of this article.

4.2 Effects of the perceptions and profiles of rural producers that affect the adoption or nonadoption of bioinputs

Table 3 and Table 4 present three binomial logistic regression analysis models in which the effect of the perception variables (based on the statements about the perception of bioinput technology answered by the producers) and the profile of the respondents in relation to the variable of technology adoption are presented. In the first model, the isolated effect of perceptions is considered, whereas in the second model, the age variable is added, whereas in the third model, whether the producer declares himself to be a family farmer is added. Neither the gender profile nor the type of production could be considered because both violate the minimum assumption for the number of respondents for each category (HAIR et al., 2009). The production area and farm area cannot be used in the analysis because they have multicollinearity, i.e., they have a direct correlation with whether they are family farmers, as these characteristics tie the size of the farm to be categorized as such (between other aspects) according to the law (Law No. 11,326, of July 24, 2006). This fact greatly reduces the measures of fit of the model.

Table 3 - Measures of Model Fit

Model	Deviation	AIC	R^2_{adj}	Global Model Test χ^2	Df	p
1	67.3	85.3	0.439	52.8	8	< .001
2	64.5	84.5	0.463	55.6	9	< .001
3	41	63	0.659	79.1	10	< .001

Source: survey data

Table 4 - Binomial regression analysis (LOGIT) of the factors that contribute to the adoption (or lack thereof) of bioinput by grain producers in the Brazilian Cerrado region.

Predictor	Estimates	Standard error	Z	P	Odds Ratio
MODEL 01					
Intercept	6.173	1.546	3.994	< .001	479,516
Decrease_agroche	-0.581	0.463	-1.255	0.209	0.559
Prioritize_bio	0.052	0.405	0.129	0.898	1.054
Pressed_bio	-0.039	0.407	-0.097	0.923	0.961
Requested_bio	-0.034	0.368	-0.094	0.925	0.966
Able_bio	-0.358	0.425	-0.842	0.400	0.699
Motivation_bio	-0.474	0.427	-1.111	0.267	0.622
Willingness_bio	-0.594	0.501	-1.186	0.236	0.552
Interest_bio	0.010	0.625	0.016	0.988	1.010
MODEL 02					
Intercept	9.041	2.586	3.497	< .001	8,442,132
Decrease_agroche	-0.521	0.466	-1.117	0.264	0.594
Prioritize_bio	0.049	0.418	0.117	0.907	1.050
Pressed_bio	-0.097	0.411	-0.236	0.814	0.908
Requested_bio	-0.113	0.356	-0.317	0.751	0.893
Able_bio	-0.329	0.423	-0.776	0.438	0.720
Motivation_bio	-0.526	0.434	-1.211	0.226	0.591
Willingness_bio	-0.625	0.505	-1.238	0.216	0.535
Interest_bio	-0.007	0.633	-0.010	0.992	0.994
Age	-0.055	0.034	-1.629	0.103	0.947
MODEL 03					
Intercept	6.265	3.406	1.839	0.066	525,662
Decrease_agroche	-1.015	0.619	-1.641	0.101	0.362
Prioritize_bio	0.434	0.529	0.820	0.412	1.543
Pressed_bio	0.075	0.555	0.135	0.893	1.078
Requested_bio	-0.487	0.470	-1.036	0.300	0.614
Able_bio	0.073	0.523	0.140	0.889	1.076
Motivation_bio	-0.384	0.670	-0.574	0.566	0.681
Willingness_bio	-0.609	0.724	-0.841	0.400	0.544
Interest_bio	-0.068	0.809	-0.084	0.933	0.934
Age	-0.060	0.044	-1.362	0.173	0.942
Fam_Agr: Yes – No	4.084	1.105	3.696	< .001	59.387

Source: survey data. Note: the results represent the odds ratio of applying bioinputs

Table 3 presents the fit measures of Model 1, with only the technology perception factor variables; Model 2, with the inclusion of age; and Model 3, with the inclusion of the self-declaration of family farmers. In all three models, the significance of the global model is observed; however, it is only in Model 3 that there is a significant factor that influences the adoption of bioinputs: not being a family farmer. Table 4 shows the three models and highlights the family farmer factor, which has a significance level of 1%, with an odds ratio of 59.387.

Thus, the fact that rural producers know that bioinput technology could be considered a first stimulus for its use, however, this fact, demonstrated with perception factors, makes it clear that there are no differences between the groups that use and do not use such technology. Age, by sequence, also had no influence on the adoption of technology by producers. Finally, being a family farmer or not has a significant effect on the adoption of bioinputs in the field: the analyses show that not being a family farmer increases the odds ratio of these farmers using bioinputs by 59 times. That is, nonfamily farmers who are knowledgeable about bioinput technology are expected to have a 98% chance of adopting bioinputs and a 2% chance of not adopting bioinputs. Owing to the high accuracy, specificity and sensitivity of the model, it is possible to predict this profile of producers with high accuracy in the adoption of bioinputs.

After the binomial logistic regression analysis of the data presented, it was possible to observe in the model represented in Table 4 that the only factor that significantly influences the adoption or nonadoption of bioinputs by rural grain producers in the Brazilian Cerrado is self-declared family farmers. Thus, it is possible to observe that age and perceptions regarding the technology of bioinputs do not have a significant influence at the 1% level on the decision to adopt (or not use) bioinputs.

To visualize these results more visually, Figure 4 shows an estimate of the marginal influence of the characteristic "Family Farmer" (Fam_Agr), in which the average of the other factors estimated in Model 2 is considered and only the fact that being a family farmer or not varies and how this affects the distribution of probabilities of adoption of this new technology (the use of bioinputs).

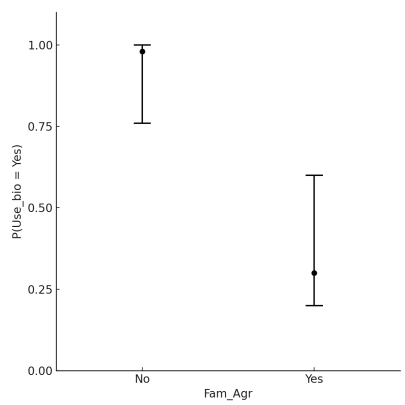

Figure 4 – Marginal effect on the probability distribution of whether the farmer is a family member.

Figure 4 shows that the distribution of nonfamily farmers is much greater and greater (because the minimum value observed was above 75%) than the distribution of family farmers and that the average probability (the point on this straight line) of the nonfamily farmer is also much greater and much closer to the maximum value obtained (100% probability). Once we have seen the main characteristics for this use of technology, now, in the next part of the article, we will see the main barriers and/or limitations for this adoption and/or for the increase of this use.

4.3 Perceptions of rural producers regarding the barriers/limitations that prevent the adoption of or increase the use of bioinputs

To analyze the limitations of the adoption and increase in the use of bioinputs on rural properties, farmers were asked to rate the importance of the following statements: i) lack of knowledge on the subject limits the use of bioinputs (Lack_of_knowledge); ii) the lack of access to extension projects on the use of bioinputs makes their application difficult (Lack_TARE_use_bio); iii) the lack of access to extension projects on the management of bioinputs hinders their use (Lack_TARE_management_bio); iv) the lack of knowledge about the production of bioinputs on their farm limits their use (Lack_known_bio_product); v) the lack of specific tax incentives for the application of bioinputs limits their use (Absence_tax_incentive_bio); vi) the lack of certification of bioinputs hinders their adoption (Lack_bio_certification); vii) the specificity of the bioinputs limits their use (High_specificity_bio); viii) the specificity of management limits their use (High_specificity_management_bio); ix) the absence of cooperatives to help produce bio-inputs limits their use (No_coop _prod_bio); x) insufficient technical assistance hinders the adoption of bioinputs (Lack_TARE_bio); xi) poor quality technical assistance hinders adoption of the use of bioinputs (TARE_without_quality_bio); xii) lack of dissemination of bioinputs limits their use (Lack_disclosure_bio); and xiii) lack of awareness of bio-inputs limits their use (Lack_conscience_bio).

The classification was carried out using a 5-level Likert scale, with the following options: 1) not important; 2) not very important; 3) neither important nor unimportant; 4) important; 5) very important, as shown in Figure 5.

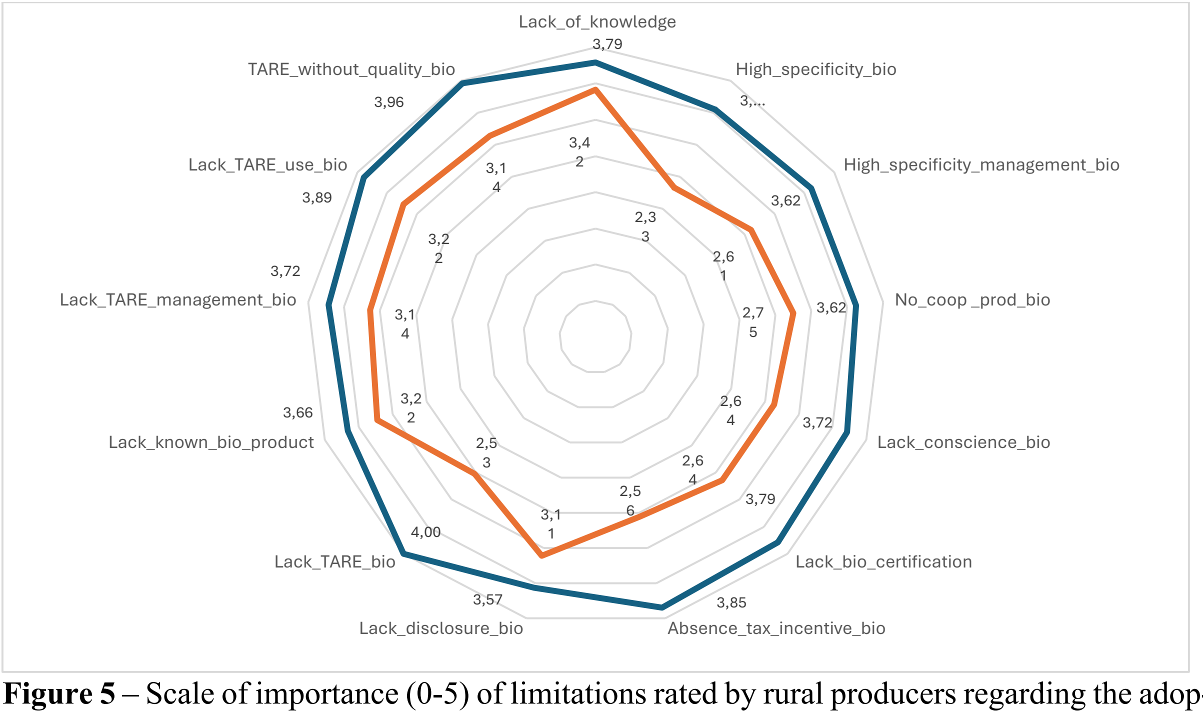

Figure 5 – Scale of importance (0-5) of limitations rated by rural producers regarding the adoption or increased use of bioinputs on their properties. The blue curve represents the limitations indicated by producers who adopt the use of bioinputs, and the orange curve represents the limitations indicated by producers who do not adopt the use of bioinputs.

Figure 5 shows evidence that the lack of technical assistance and rural extension (TARE) is a significant aspect limiting the adoption or limiting the increase in the use of bioinputs by rural grain producers in the Cerrado, which was confirmed in Table 5.

Table 5 - Binomial regression analysis of the factors that limit the adoption or increase in the use of bioinputs by producers

Predictor	Estimates	Standard error	Z	p	Odds Ratio
Intercept	-3.192	1.509	-2.116	0.034	0.0411
Lack of bio knowledge	-0.2476	0.44	-0.563	0.574	0.7807
Lack_TARE_use_bio	-0.5114	0.677	-0.755	0.450	0.5996
Lack_TARE_management_bio	0.7849	0.649	1.21	0.226	2.1921
Lack_known_bio_product	-0.3962	0.34	-1.165	0.244	0.6729
Absence_tax_incentive_bio	0.0565	0.322	0.175	0.861	1.0581
Lack_bio_certification	0.0707	0.335	0.211	0.833	1.0732
High_specificity_bio	0.4198	0.515	0.814	0.415	1.5216
High_specificity_management_bio	-0.079	0.471	-0.168	0.867	0.924
No_coop _prod_bio	-0.4698	0.436	-1.078	0.281	0.6251
Lack_TARE_bio	1.3518	0.489	2.763	0.006	3.8644
TARE_without_quality_bio	0.2604	0.37	0.704	0.481	1.2974
Lack_conscience_bio	1.7202	0.664	2.592	0.197	5.5854
Lack_disclosure_bio	-1.7311	0.697	-2.485	0.130	0.1771

Source: survey data. Note: the results represent the odds ratio of applying bioinputs

According to Table 5, rural producers who do not have access to a satisfactory TARE have a 3.8-fold greater odds ratio of not adopting or, if they do, not increasing the use of bioinputs on their property. That is, a producer with a lack of TARE is 3.8 times more likely to not adopt bioinputs than to adopt them. It is clearly a limiting element in the use and expansion of technology.

4.4 Means of communication/dissemination that enable rural producers to learn about and keep up to date with bioinput technology

To analyze the means of communication/dissemination that allowed the rural producers to update their knowledge about the bioinput technology, the study participants were asked the following options regarding the source of knowledge about the technology and the source of updating and monitoring of changes in the technique: i) events/training/Lectures (Events); ii) input/consultancy companies (Companies); iii) research and education institution (University); iv) technical assistance and rural extension (TARE); v) digital communication (websites, webinars, podcasts, videos) (digital_media); vi) printed information (books, magazines, leaflets) (Print_material); vii) relatives (relatives); viii) other farmers or Professionals in the field (Professionals); ix) training/Demonstration (Demonstration); x) government agency (Gov); xi) non-governmental organizations (NGOs); and xii) agricultural regenerative organizations (NGO_regenerative), as shown in Figure 6:

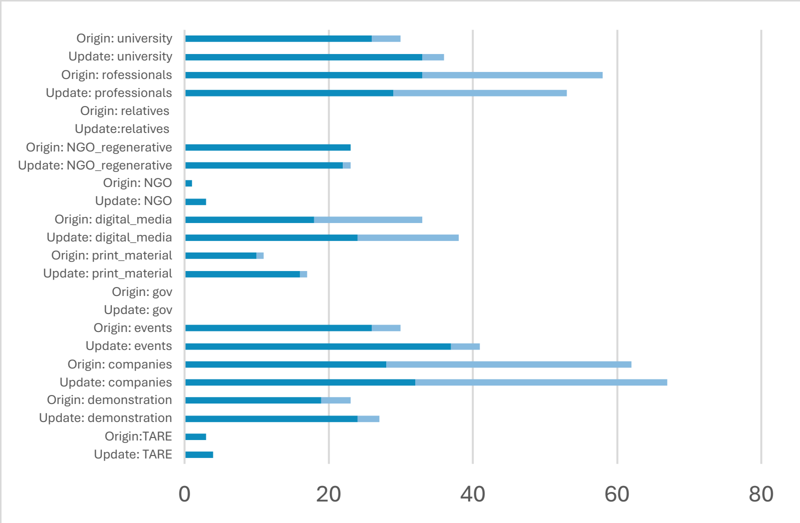

Figure 6 - Number of respondents who indicated the means of communication/dissemination used by rural producers as a source of access to knowledge about bioinputs (origin) and technology updates (update), considering those who adopted (dark color) and those who did not adopt (light color) technology.

Analyzing Figure 6, it is not possible to observe explicit differences regarding sources of information (either to learn or to update) between the means of communication and dissemination used by rural producers. The only observation is that there was no mention of sources of information originating from the government (governmental) or from relatives. For this reason, it is necessary to perform a statistical analysis to verify whether there is a difference between the means of knowledge cited by producers and whether they adopt the technology. Table 6 presents the statistical analysis of the data, showing the significance (or not) of the differences observed, except for the government source and relatives (not indicated by the producers).

Table 6 – Comparison between groups via the Mann–Whitney U test for the analysis of the means of communication/dissemination used by farmers that enabled knowledge about the technology of bioinputs.

Source of Knowledge	Origin		Update	
	Statistics	p value	Statistics	p value
Events/Training/Lectures	557	< .001	394	< .001
Input Companies	592	< .001	603	< .001
Research and Education Institution (Universities)	592	< .001	440	< .001
Rural Extension	900	0.153	882	0.096
Digital Media (websites. webinars. podcasts. videos)	881	0.466	893	0.555
Printed information (books. magazines. pamphlets)	801	0.025	693	0.001
Other Farmers/Professionals in the field	718	0.491	602	0.264
Training/Demonstration	936	0.009	900	< .001
Non-Governmental Agency	557	0.423	394	0.153
Regenerative Agricultural Organizations	592	< .001	603	< .001

Source: research data

According to Table 6, it is possible to observe a significant difference at the 1% level between the sources presented:

- Events/Training/Lectures (Events);
- Input/Consultancy Companies (Companies);
- Research and Education Institution (University);
- Printed information (books, magazines, pamphlets) (Print_material);
- Training/Demonstration (Demonstration);
- Regenerative Agricultural Organizations (NGO_regenerative).

This difference demonstrates that such information sources, both for initial knowledge of the technology and for the maintenance of this knowledge, have a significant influence on the adoption of bioinput technology. However, it is valid to consider that such influence can be positive or negative. For this reason, another statistical tool, the chi-square test, was used. He evaluated the association between each of these knowledge sources with respect to whether to adopt the technology. Thus, identifying the sources of information for rural producers regarding bioinput technology is only part of this study. After that, we seek to understand how rural producers are affected by them in choosing the most appropriate channels of communication of information, and this information is presented below.

Table 7 presents the chi-square test analysis of the data obtained regarding the main sources of knowledge communication used by rural producers who adopt or do not adopt bioinputs, either for knowledge of the technology or for improvement and technology updates.

Table 7 – Chi-square test on the association between rural producers who use (yes) or do not use (no) bioinputs regarding sources of knowledge and technical updating.

Use_bio		Events No	Events Yes	Total
No	obs freq	32	4	36
	exp freq	23.9	12.1	36
	chi-square	2.8	5.4	8.2
Yes	obs freq	29	27	56
	exp freq	37.1	18.9	56
	chi-square	1.8	3.5	5.3
Total	obs freq	61	31	92
	exp freq	61	31	92
	chi-square	4.5	9	13.5

Pearson chi-square = 13.5023 Pr = 0.000

Use_bio		Companies No	Companies Yes	Total
No	obs freq	2	34	36
	exp freq	11.7	24.3	36
	chi-square	8.1	3.9	12
Yes	obs freq	28	28	56
	exp freq	18.3	37.7	56
	chi-square	5.2	2.5	7.7
Total	obs freq	30	62	92
	exp freq	30	62	92
	chi-square	13.3	6.4	19.7

Pearson chi-square = 19.6970 Pr = 0.000

Use_bio		University No	University Yes	Total
No	obs freq	32	4	36
	exp freq	23.9	12.1	36
	chi-square	2.8	5.4	8.2
Yes	obs freq	29	27	56
	exp freq	37.1	18.9	56
	chi-square	1.8	3.5	5.3
Total	obs freq	61	31	92
	exp freq	61	31	92
	chi-square	4.6	8.9	13.5

Pearson chi-square = 13.5023 Pr = 0.000

Use_bio		Print_Material No	Print_Material Yes	Total
No	obs freq	35	1	36
	exp freq	31.7	4.3	36
	chi-square	0.3	2.5	2.8
Yes	obs freq	46	10	56
	exp freq	49.3	6.7	56
	chi-square	0.2	1.6	1.8
Total	obs freq	81	11	92
	exp freq	81	11	92
	chi-square	0.6	4.1	4.7

Pearson chi-square = 4.7333 Pr = 0.030

Use_bio		Demonstration No	Demonstration Yes	Total
No	obs freq	32	4	36
	exp freq	27	9	36
	chi-square	0.9	2.8	3.7
Yes	obs freq	37	19	56
	exp freq	42	14	56
	chi-square	0.6	1.8	2.4
Total	obs freq	69	23	92
	exp freq	69	23	92
	chi-square	1.5	4.6	6.1

Pearson chi-square = 6.0847 Pr = 0.014

Use_bio		NGO regenerative No	NGO regenerative Yes	Total
No	obs freq	35	1	36
	exp freq	25.8	10.2	36
	chi-square	3.3	8.3	11.6
Yes	obs freq	31	25	56
	exp freq	40.2	15.8	56
	chi-square	2.1	5.3	7.4
Total	obs freq	66	26	92
	exp freq	66	26	92
	chi-square	5.4	13.6	19

Pearson chi-square = 18.9437 Pr = 0.000

Source: research data

Table 7 clearly shows that some sources of knowledge, whether as a new practice or to maintain knowledge, have positive effects, while others have negative effects. All test results were significant at the 5% level, thus indicating a strong association between technology adoption and the source of knowledge. When the expected number of respondents is greater and the actual result is smaller, it is expected that the item has a negative association, i.e., a greater number is expected than was observed. The reverse is also true. According to the results, the following conclusions can be drawn:

- Events/Training/Lectures (Events) have a positive influence on producers. Producers who discover the technology and/or update themselves through events have a positive influence on its adoption.
- Input/Consultancy Companies (Companies) have a negative influence, either as an initial source of knowledge or update. The source of input companies negatively reverberates in the adoption of the practice.
- Research and education institutions (University) have positive effects on technology adoption.
- Printed information (books, magazines, leaflets) (Print_material) has a positive effect on technology adoption.
- Training/Demonstration (Demonstration) has a positive effect on technology adoption.
- Agricultural Regenerative Organizations (NGO_regenerative) have a positive effect on technology adoption.

5. CONCLUSION AND FINAL CONSIDATIONS

According to the data presented, the main conclusions of this study are as follows: a) there is evidence that nonfamily farmers may be the most appropriate audience for the adoption and expansion of bioinputs, and b) there is a need for investment in qualified technical assistance to assist producers in decision making and in the continued use of biological products.

Although the study was conducted in the Brazilian Cerrado region, with grain producers, especially soybeans, it serves as a guideline for the bioinput market in general and provides an opportunity for further study in other regions and with other agricultural products.

Notably, rural producers are increasingly informed about the importance of using products of biological origin; however, there is a lack of understanding of how the adoption and continued use of these products should be performed. Thus, it is essential that the technical assistance and consulting services are adequately trained so that they can assertively meet the demands of rural producers. Therefore, making farmers aware of the importance of their role in establishing more balanced agriculture is essential for successful learning about the use of biological products, which require specific viability conditions, as well as the use of appropriate equipment for their conservation and application in the field.

In addition, the results of this study show that there is specificity in the choice of sources of information on bioinputs that influences the behavior of rural producers regarding the adoption and nonadoption of bioinputs. Thus, the rural producers who chose not to adopt the use of bioinputs on their properties used the input supply companies, together with the technical consultancy of resale companies, as the main sources of knowledge and updates regarding biological products.

On the other hand, rural producers who chose to adopt the use of bioinputs on their properties were informed and kept up to date through events, training courses, lectures, educational and research institutions and regenerative agricultural organizations, acting as active actors in the learning process and, concomitantly, as disseminators of the experiences acquired with agricultural practices resulting from the adoption of new technologies and agricultural innovations.

Thus, offering various sources of technical knowledge can influence the interest of rural producers in relation to the adoption of this technology in the field. This information is important for the bioinput industry to understand and thus better manage the main forms of technology diffusion that reach agricultural producers.

Public policies related to biological inputs, such as the National Bioinputs Program, created in 2020, may be important for South American countries, such as Brazil. This is because the federal government's promotion of biological products does not have the objective of breaking away from conventional agriculture or chemical inputs but rather is a way of promoting the coexistence of chemical and biological inputs toward the so-called bioeconomy. Biodiversity is a resource that can be explored and used to improve the ecological sustainability of agriculture.

Thus, knowledge, information sharing, consulting and quality technical assistance, together with appropriate environmental policies and legislation, as well as the establishment of environmental, social and economic indicators clearly result in motivations for the adoption and expansion of bioinputs.

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