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Diagnosis of directed pollination services in apple orchards in Brazil

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Abstract - The pollination services performed by *Apis mellifera* are essential for the high-quality apple production. The aim of this study was to obtain information about the pollination services used in the municipalities of Vacaria-RS e São Joaquim-SC, the main apple-producing regions in Brazil. Semi-structured interviews were conducted with apple growers and technicians responsible for the orchards during 2013 and 2015. The obtained information was: a) cropping systems; b) use of pollination services; c) number of hives per hectare during flowering; d) renting value of hives; e) mortality of colonies; f) agrochemicals used on flowering; g) presence of native bees on flowering. In Vacaria and São Joaquim, respectively, 70% and 68.6% of the apple growers use the integrated apple production as their production model. The directed pollination is used by 100% and 90.0% of respondents respectively, from which, 80% and 47.1% opt for the hive rent. On average, three hives were used per hectare in both regions. The average cost is U$ 17.52 and U$ 17.74 per hive, respectively. During the flowering period, insecticides and fungicides are used by 100% and 97.2% of the apple growers. The highest mean percentage of mortality of colonies during flowering was reported in Vacaria, 11.8%. Native bees are often found in apple flowers. The development of management strategies for the conservation of domestic and wild pollinators is essential.

Index Terms: *Apis mellifera,* interview, *Malus domestica,* Pollination diagnosis.

Diagnóstico dos serviços de polinização comercial em pomares de macieiras no Brasil

Resumo - Os serviços de polinização realizados por *Apis mellifera* são fundamentais para a produção de maçãs com qualidade. O objetivo deste estudo foi obter informações sobre os serviços de polinização utilizados nos municípios Vacaria-RS e São Joaquim-SC, principais regiões produtoras de maçãs no Brasil. Entrevistas presenciais com questionários semiestruturados foram realizadas junto aos maleicultores e técnicos responsáveis pelos pomares, entre 2013 e 2015. As informações obtidas foram: a) sistema de cultivo adotado; b) emprego de serviços de polinização; c) número de colmeias por hectare na floração; d) valor do aluguel de colmeias; e) mortalidade de colônias; f) insumos químicos utilizados na floração; e g) presença de abelhas nativas na floração. Em Vacaria e São Joaquim, 70% e 68,6% dos maleicultores utilizam a produção integrada de maçã como modelo produtivo. A polinização comercial é utilizada por 100% e 90,0% dos entrevistados, respectivamente, dos quais 80% e 47,1% optam pelo aluguel de colmeias. Em média, são utilizadas três colmeias por hectare em ambas as regiões. O custo médio é de R$ 56,60 e R$ 57,30 por colmeia, respectivamente. Durante a floração, agrotóxicos foram utilizados por 100% e 97,2% dos entrevistados. O maior percentual médio de mortalidade de colônias foi relatado em Vacaria, 11,8%. Abelhas nativas são frequentemente observadas na floração. É imprescindível o desenvolvimento de estratégias de manejo para a conservação de polinizadores domésticos e silvestres.

Termos para indexação: *Malus domestica, Apis mellifera*, Diagnóstico da polinização, entrevistas.

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Introduction

Among the temperate climate fructiferous trees grown in Brazil, the *Malus domestica* Borkh apple tree has shown the largest expansion in terms of area and production volume over the last thirty years (PETRI et al., 2011). Currently, orchards occupy 36.6 thousand hectares, considering that the municipality of Vacaria, with 7.1 thousand hectares, in the State of Rio Grande do Sul, and the municipality of São Joaquim, with 8.3 thousand hectares, in the State of Santa Catarina, are responsible for 41.4% of the Brazilian apple production, in addition to jointly owning approximately 42.1% of the total cultivated area in Brazil (IBGE, 2015).

The assurance of good productions on apple orchards depends on an efficient pollination, which is also related to the compatibility between pollen-stigma and to the coinciding flowering season (KVITSCHAL et al., 2013), as well as to the indispensable presence of bees (VIANA et al., 2014). According to Abrol (2012), the value of bees as pollinators is much higher than their value as honey producers. This statement was corroborated by Losey and Vaugan (2006), who attributed to the pollination by *Apis mellifera* and native bees, a mean increase on the production value of US$ 1.58 billion on the apple tree culture alone during 2001 and 2003. However, it is observed that some populations of pollinators are suffering a reduction, and this may make agricultural activities unfeasible and cause severe economic damages (POTTS et al., 2010).

The pollination services are known for offering substantial benefits for the agriculture and, consequently, for human populations (BREEZE et al., 2011). On apple tree cultures, an example of mandatory interaction is observed, in which the dependence on bees to pollinate the flowers and the development of the fruits may reach 100%, Losey and Vaughan (2006). The effective pollination of the flowers of apple trees not only results in an increase in productivity (SALOMÉ, 2014), but also in terms of quality, since the fruits with pollination deficiency show an irregular shape and reduced market value (ABROL, 2012).

Over the last years, an increase was recorded on the productivity of apple orchards, resulting on a higher produced volume, with put the increment of the cultivated area. Comparing the 2001/2 and 2014/15 crops, while the planted area increased around 28.7% (26 thousand to 36.5 thousand hectares), the productivity increased 50% (650 thousand to 1.3 million tons), creating a total production value of approximately U$ 317 million per year (IBGE, 2015). The productivity increase on orchards is associated to the use of new cultivars, to the plant density, and to advanced culture techniques and practices (PETRI et al., 2011). Despite the evidences of the productivity increase of orchards, the recommendations for the management of pollinators did not change over time.

According to Lebuhn et al. (2013), emphasis has been given to diagnostic and monitoring programs at the global level in order to examine the situation of pollinators, their management and decline levels of the species responsible for the pollination services. This information is fundamental in order to get to know the scenario, and suggest adequate strategies and recommendations to the management of domestic and native pollinators on the different cultures.

The aim of this study was to gather, analyze and provide information on the current situation of the main apple-producing regions in Brazil, regarding the pollination services, mortality, management of domesticated hives and presence of native bees, in addition to discussing and suggesting management and preservation strategies for these insects.

Materials and Methods

The information on the pollination services on the apple tree culture was obtained during two periods: 2013/2014 crop (December 2013 to May 2014) and 2014/2015 crop (December 2014 to June 2015), on the municipalities of Vacaria, RS (28º30'44"S, 50º56'02"W and 971 m of altitude) and São Joaquim, SC (28º16'33"S, 49º56'12"W and 1,406 m of altitude). During this period, 110 farmers/landowners and responsible technicians from producing establishments were interviewed, through the use of structured questionnaires in order to obtain the quantitative data, and a second, semi-structured part, in order to obtain the qualitative data and the opinion of the participants. The regions of Vacaria and São Joaquim were chosen because, in addition to the fact that they represent a large part of the planted area of apple orchards in Brazil, they are references in high-technology production; in addition, they have both orchards managed by familiar agriculture and orchards managed by large business groups.

In order to identify the farmers and establishments that would significantly represent the situation of the pollination services on the culture, members of entities connected to the apple-production sector were queried: Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri), Empresa Brasileira de Pesquisa Agropecuária (Embrapa Uva e Vinho), Associação dos Produtores de Maçã e Pera de Santa Catarina (AMAP), Associação Brasileira dos Produtores de Maçã (ABPM), Associação dos Engenheiros Agrônomos da Serra Catarinense (ASSEA), Cooperativa Agrícola de São Joaquim (Sanjo), Cooperativa Regional Serrana (Cooperserra), Cooperativa Agrícola Frutas de Ouro, Mussato Consultoria Rural Ltda, Schio Agropecuária Ltda and agricultural input resellers from both evaluated regions.

The topics discussed on the interviews were: a) the

farming and management system used on the culture; b) hiring of pollination services; c) number of *Apis mellifera* hives used per hectare during pollination; d) renting value per hive; e) percentage of mortality of verified hives during the pollination period on the 2013/14 and 2014/15 crops; f) pesticides used during flowering; g) presence of native bees during flowering; and h) information on the main difficulties found by the farmers and technicians related to the pollination services. The value charged for the rent of hives during both crops was obtained by the mean of the referred value on each interviewed establishment on both regions. For the conversion of values, the commercial dollar exchange rate was used on 07/02/2016 (US$ 1.00 = R$ 3.23).

The data and information obtained were charted and grouped into tables, as well as transformed into percentage or mean values for the presentation and discussion of the results. In addition, the obtained data were categorized according to the characteristic of each question, and were analyzed using IBM SPSS Statistics 21.0 for Windows(r) (SPSS Inc, 2013) for descriptive statistics (means and percentages) and the Chi square test ($p \leq 0.05$) to verify the significance of observed frequencies.

Results and Discussion

The culture system used in Vacaria and São Joaquim converges to the Integrated Apple Production (IAP), representing 70 and 68.6% of the total interviewed farmers, respectively. There was no statistically significant association between the production systems for the two regions (Table 1). On both studied regions, the conventional culture is still used by approximately 30% of the interviewees (Table 1), where cultural practices are used in combination with phytosanitary treatments that follow a fixed schedule, not taking into consideration the monitoring indexes of plagues and diseases.

The organic production of apples is incipient on both regions, with a reduced economic representation (Table 1). This fact is due mainly to the pressure caused by plagues such as the South American fruit fly *Anastrepha fraterculus*, the Oriental fruit moth *Grapholita molesta,* and the apple scab *Venturia inaequalis* (BLANCHET et al., 2012). Without an adequate and efficient control, these phytosanitary problems may severely compromise the apple production on these regions.

The pollination services through the management of hives of *A. mellifera* on apple tree orchards are used by 100% of the interviewees on the region of Vacaria, and by 90% of the interviewees in São Joaquim (Table 1). The farmers and technicians from São Joaquim who stated they did not use directed pollination with bees on the orchards (10%) reported that there is an intensive visitation by *A. mellifera* to the apple tree flowers from existing colonies on the native woods or originated from neighboring orchards, as well as from native bee species. Due to this reason, they do not make use of the managed pollination services on the orchards.

The renting of hives is a practice that is used by most growers. In relation to the producers that use directed pollination, the Vacaria region presents the highest percentage of adhesion to the hiring of pollination services (80.0%), when compared to São Joaquim with 47.1% (P=0.002) (Table 1). Another highlight is a representative percentage of 52.9% of apple producers with their own apiaries in the region of São Joaquim. Possibly, this reality is due to the reduced size of the orchard areas in that region, which require a reduced total number of hives. Therefore, the maintenance of small apiaries is economically more feasible than paying for third-party services with the renting of hives.

On this research, the mean value for renting the hives during both crops was U$ 17.52/unit in Vacaria and U$ 17.74/unit in São Joaquim (Table 2). Freitas and Imperatriz-Fonseca (2005) estimated that in Santa Catarina, from 45 to 50 thousand hives were rented per flowering, at an approximate cost of U$ 12.38/unit in order to meet the productive chain of apple in the State. According to the authors, this partnership with the apple producers allowed a return of approximately US$ 620,000.00 per year to apiarists. In Rio Grande do Sul, on the region of Vacaria alone, the apple orchards receive approximately 15.5 thousand hives/year, representing an annual income for the apiarists of approximately US$ 217,000.00 with this activity (APACAME, 2014).

The mean density of the hives on both regions is similar, and approximately three hives are used per hectare during the flowering period (Table 2). According to Salomé (2014), directed pollination with the use of hives of *A. mellifera* follows the model developed during the 1970's, through the initiative of the Apiculture Institute of Santa Catarina. In order to conduct the directed pollination, during that time, a number between 0.5 and 3 hives/ha-^{1} was recommended, and it varied according to the age of the orchards (WIESE, 1974). In other parts of the world, the recommended number of hiver per hectare in order to assure the pollination of the apple tree flowers may vary between 2 to 7 (ABROL, 2012; VIANA et al., 2014).

Regarding the management of pollinators, the need to introduce healthy hives with a large number of field bees during the flowering periods is observed. This procedure improves the pollination services on the culture of apple trees, assures a larger number of fertilized flowers and fruits of a higher quality and symmetry. The previous evaluation of these colonies is a preponderant factor for the success of the pollination service on the apple tree culture.

The studies related to the directed pollination in apple trees in Brazil are scarce, and they were initiated from the Golden Delicious, Starkrinson Spur and Golden Spur cultivars (WIESE, 1974), which are currently no longer produced. During that time, the cultures were conducted according to the Cup system, with density

between 550 to 800 plants ha-[1] (WIESE, 1974). Currently, by using genetic material that is free from viruses, dwarf rootstocks and a central leader conduction system, it is possible to reach 1,500 to 3,500 plants ha-[1] (PETRI et al., 2011). This factor considerably increases the number of flowers to be pollinized per area (SALOMÉ, 2014). Taking into consideration the increase on the density of plants and flowers on orchards, and the maintenance of the pollination practices used for decades, it is considered that the current pollination system used on apple orchards has some deficiencies, and that it is necessary to increase the number of hives per area and improve the management of managed pollinators, therefore, improving the pollination efficiency on the orchards.

Salomé (2014) recommends, for the apple tree culture, an increase of at least 100% on the number of hives for each hectare (going from three to six hives), in addition to the graduate introduction of 50% of the hives with an index of 15% to 20% of flowers. If the hives are allocated before this index, there is a strong trend to search for alternate sources of foods outside the orchard (ABROL, 2012). The rest of the hives must be introduced during the full-bloom stage of the apple tree flowers. These recommendations aim at reducing the visitations to the apple flowers after the complete acknowledgement and gradual increase of the foraging area by the bees, resulting in the search for other sources of pollen and nectar over the apple tree flowers. According to Salomé (2014), the effective fructification on cultivars such as Fuji Suprema, Galaxy and Imperial Gala may be duplicated with a larger number of bees visiting the flowers. This information is economically relevant, considering that 90% of the national production of apples is comprehended by the Gala and Fugi cultivars and their clones (PETRI et al., 2011).

Despite the pollination deficit shown by the apple tree culture under some situations (VIANA et al., 2014), the satisfaction indexes of the interviewees as to the pollination services were high both in Vacaria, 95%, and in São Joaquim, 90.0% (Table 2). These results may be related to the production obtained on the orchards, since several apple producers reach productivities around 70 tons per hectare, which is a significant value, when compared to the national mean productivity, around 35 tons (IBGE, 2015). In addition, in order to assure this yield, several apple producers turn to the application of hormones, such as thidiazuron, which increases the effective fructification (PETRI et al., 2001), therefore, assuring high productivities. Another possibility for the high index of satisfaction is relation to the pollination conducted by native bees (BLÜTHGEN and KLEIN, 2011), which visit the apple tree flowers, contributing for the reduction on the pollination deficit.

Regarding the mortality of hives of *A. mellifera,* both regions showed similar results (Table 2). 42.5% and 47.6% of the interviewees on the regions of Vacaria and São Joaquim observed the mortality of colonies during the pollination period on both evaluated crops respectively. Even with the high number of mortality reports, and some interviewees having reported considerable losses (up to 50% of the hives), the mean percentage of losses, per property, during the flowering period did not exceed 12% on both evaluated regions (Table 2). However, in Brazil, there are no studies on the level of apiaries related to the behavior and mortality of the colonies after the hives are removed from apple orchards. These studies are majorly important in order to elucidate possible sub-lethal effects caused during the exposure of the bees during the pollination period of the culture.

The partnership between apple producers and apiarists in Brazil has been successful for a long time; however, this relationship may suffer significant changes over a short period of time. Currently, there are frequent reports by apple producers that question the quality of the hives available for pollination (hives that get to the orchards with a small brood area and a reduced number of field bees), and there are also complaints by the apiarists that observe the decline of colonies that return from the orchards after the flowering of the apple tree (ARIOLI et al., 2015).

Spraying fungicides and/or insecticides during the flowering period is used on both regions. In Vacaria, 100% of the interviewees used these products during the flowering period on both evaluated crops. In São Joaquim, only 2.8% of the interviewees (organic apple producers) stated they did not use chemical products during the flowering period (Table 1). Among the main pesticides mentioned are the following insecticides: Rimon® (Novaluron), Altacor® (Chlorantraniliprole) and Dipel® (*Bacillus thuringiensis*), and the fungicides: Dithane® (Mancozeb), Frowncide® (Fluazinam), Captan® (Captan), Delan® (Dithianon) and Mythos® (Pyrimethanil). The aim of these applications is to control/prevent diseases such as the apple scab *Venturia inaequalis* (BLANCHET et al., 2012) and for the control of caterpillars (NUNES et al., 2013). In that sense, it is fundamental to conduct specific studies on the effect of these products, mainly the sub-lethal ones. In the case of novaluron, in field, no effects of disorientation and/or reduction on the number of visits by adult *A. mellifera* bees on the apple tree flowers are observed when the insecticide is applied (ARIOLI et al., 2015). However, these authors observed that, throughout time, the weight of the hives was reduced in up to 50%, showing sub-lethal effects on the colonies. Although they are considered as safer for the insects (since they act specifically on fungi), fungicides may also interrupt the foraging behavior of the bees due to their repelling effect. In addition, when taken to the hive together with the nectar and pollen, they may affect the development of larvae, and they may also harm the immunological system of bees, increasing the infections by diseases such as the one caused by *Nosema cerane* (PETTIS et al., 2013).

The density and appeal of the flowers from agricultural crops in full bloom, contaminated by the application of certain pesticides, may cause the death

of pollinators, affect the behavior of foraging bees, and, therefore, reduce the vigor of the colonies (JIVAN, 2013). This fact led the United States to suggest the creation of "pesticide free zones", prohibiting applications during the flowering period of the agricultural crops (POLLINATOR HEALTH TASK FORCE, 2015).

Native bees, including solitary and social species, are the most frequent flower visitors on several of the plants, and the most important pollinators of several angiosperms, including crops (GARIBALDI et al, 2013). According to the interviewees of both regions, this group is usually observed during the flowering period of apple trees (Table 3). In addition, 95% and 96.4% of the interviewees consider native bees as important pollinating agents of this culture on the regions of Vacaria and São Joaquim, respectively (Table 3).

Due to the differences of the species and functional characteristics, more abundant pollinators able to promote the crossed pollination may increase the synergy and complementarity of the foraging, improving the quantity and quality of the pollination (BLÜTHGEN and KLEIN, 2011). Therefore, the increased diversity of pollinators may increase the definition of the fruits (or seeds) and the quality of the apples, such as the size and shape of the fruit (GARIBALDI et al., 2014).

The results of this research show the need to increase the number of hives during the flowering period, reducing the pollination deficit, which is reflected by the larger quantity and quality of the fruits. In addition, there is the need to create a closer relationship between apple producers and apiarists that work to provide pollination services, highlighting the indispensability of establishing management criteria for the culture and the directed and wild pollinators. Among them, emphasis is given to the need for professional qualification for apiarists on the preparation management of the hives for the pollination of apple trees. On the other hand, it is necessary to develop actions for the reduction and adequate management of the application of chemical products during the flowering period, as well as for the preservation of the landscape that surrounds the agricultural areas by the apple producers.

Table 1- Culture systems, use of pollination services and origins of the bees used on apple orchards on the regions of Vacaria and São Joaquim, Brazil.

Diagnosis (Census)	Regions		
	Vacaria	São Joaquim	
	%	%	P value
Culture system			ns
IAP	70.0	68.6	
Conventional	30.0	28.6	
Organic	0.0	2.8	
Use of pollination services			0.039
Yes	100.0	90.0	
No	0.0	10.0	
Origin of the bees			0.002
Rent of hives	80.0	47.1	
Particular apiary	20.0	42.9	
Without directed pollination	0.0	10.0	

*The total number of properties investigated is 110. [1]Integrated Apple Production. ns: Non-significant (P>0.05) by chi-square test.

Table 2-Profile of the apple-producing regions concerning the use of hives of *Apis mellifera* for pollination services, the rent value of the hives, the number of hives used, the satisfaction index regarding the use of directed pollination and the losses of hives during the flowering periods of the 2013/14 and 2014/15 crops.

	Regions	
Diagnosis (Census)	Vacaria	São Joaquim
Mean value of the rent[1] (U$)	17.52±0.61[2]	17.74±0.77[2]
Number of hives per hectare (un.)	2.90±0.23[2]	3.30±0.29[2]
Satisfaction index[3]		
Yes	95.0	90.0[ns]
No	5.0	10.0
Losses of hives[4]		
Yes	42.5	47.6[ns]
No	57.5	52.4
Mean of loss[5] (%)	11.8	10.3[ns]

*The total number of properties investigated is 110. [1]Mean value obtained in relation to both years in which the interviews occurred. [2](±SE): Standard error. [3]Satisfaction index of the interviewees that used the directed pollination services (N=103). [4]Percentage of interviewees that reported losses of hives. [5]Mean percentage of lost hives per agricultural establishment during the flowering in 2013/14 and 2014/15. ns: Non-significant (P>0.05) by chi-square test.

Table 3- Knowledge of the interviewed apple producers and technicians on different production regions on native bees and their importance during the flowering period of the apple tree culture.

	Regions		
Diagnosis (Census)	Vacaria	São Joaquim	
	%	%	P value
Presence of native bees on the orchards	75.0	84.6	ns
Importance of native bees for pollination	95.0	96.4	ns

*The total number of properties investigated is 110. [1]Percentage of interviewees that observe native bees on apple tree flowers. [2]Percentage of interviewees that consider native bees as important pollinators on the apple tree culture. ns: Non-significant (P>0.05) by chi-square test.

Conclusions

The Integrated Apple Production (IAP) is the main production system used in São Joaquin and Vacaria apple-producing regions. Most apple producers use pollination services by renting bee hives of *A. mellifera*. An average of three hives per hectare are used during the flowering of apple trees. The insecticides novaluron, chlorantraniliprole, *Bacillus thuringiensis* and the fungicides mancozeb, fluazinam, captan, dithianon and pyrimethanil are used during the flowering of apple trees in São Joaquim and Vacaria. The mortality index of managed hives during the flowering of apple trees is below 12%. Native bees appear frequently during the flowering of apple trees. There is a necessity to develop a conservationist management plan to preserve bees and increase the pollination of the culture.

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