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Development of Beekeeping: An Analysis Using the Technique of Principal Components

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<http://dx.doi.org/10.5772/intechopen.74223>

Abstract

Beekeeping is an economic activity of the Brazilian agricultural sector and a powerful tool to achieve sustainable development. However, beekeeping still remains a modest activity compared to other areas, with a lack of technical knowledge and beekeeping practices that need to be standardized. This study represents a proposal for the diagnosis of beekeeping, to facilitate decision-making and to provide a faster development of the beekeeping activity. We investigated the process of adoption of beekeeping practices of 28 beekeepers and the quality of the honey produced by them in the Western region of Paraná, using the technique of Principal Components Analysis after the construction of apicultural indexes. Specifically, the honey produced in the Western region of Paraná be included in the requirements of national and international legislation, but the beekeeping practices adopted still require standardization so that the beekeepers have higher honey production. Also, the transformation of variables into apicultural indexes for later use in the analysis of principal components proved to be efficient to draw a beekeeping profile. Our research proves to be efficient in accurately diagnosing beekeeping bottlenecks, which may enable better decision-making and thus attract new entrepreneurs and increase their relevance to achieve sustainable rural development.

Keywords: multivariate analysis, *Apis mellifera*, physicochemical analyses, apicultural indexes, sustainable rural development

1. Introduction

Beekeeping is an economic activity of the agricultural sector and an environmentally sustainable production model, crucial for biodiversity and agriculture [1]. Beekeeping provides additional income for many poor communities, creating new opportunities in rural areas, and improves the living conditions of many families [2, 3]. In addition, the pollination service provided by honeybees generates increases in crop yields [4] and contributes to the balance of the ecosystem and biodiversity [5].

In the economic sphere, Brazil stands out among the honey-producing countries worldwide, occupying the 8th position. In 2014, Brazil exported 25.317 tons of honey, generating exchange revenue of US \$ 98.58 million [6]. In the Brazilian scenario, Rio Grande do Sul, with a honey production of 7.286 tons, is the first State in the national ranking, followed by the States of Paraná with 5.565 tons and Santa Catarina with 4.887 tons of honey produced [7].

Although economic indicators of beekeeping show progress in the activity, its development is far below that expected for a country that has one of the largest biodiversity on the planet and conditions conducive to the beekeeping. Thus, making beekeeping more profitable, such as adopting appropriate beekeeping practices, with a consequent higher honey quality, can be an alternative to attract new entrepreneurs and increase their relevance as a means to achieve sustainable rural development. The physicochemical composition of honey is complex and can be used to verify the quality of the honey produced, as well as to improve honey extraction practices [8, 9], conservation, and storage, avoiding contamination, honey differentiation of other products, and determination of botanical origin [10].

A reliable statistical analysis, correlating information on beekeeping practices and quantity and quality of honey produced in the Western region is very important for the growth of beekeeping since in addition to the aspect of legislation these analyses can support assessments of the beekeeping profile, against many changes in the region in the last decade, thanks to the partnerships between the university and other institutions with beekeepers.

Principal Component Analysis (PCA) is a very powerful technique, but it has its limitations. It is generally used to study variance and covariance through linear combinations of q variables involved [11] and also to order data based on quantitative variables, with or without transformation [12]. PCA was initially defined for data with multinomial distributions [12], although it can be applied to binary data [13]. The objective of this study is to investigate the process of adoption of beekeeping practices and the quality of honey produced in the Western region of Paraná, proposing an alternative analysis of the data through the technique of Principal Component Analysis, using apicultural indexes constructed from binary variables and associated with quantitative variables.

2. Material and methods

2.1. Evaluation questionnaire

The study was carried out from January 2015 to June 2015 with 28 cooperative beekeepers from the Cooperativa Agrofamiliar Solidária dos Apicultores of the West Coast of Paraná,

located in the county of Santa Helena, State of Paraná, Brazil (latitude 24°51'37"S and longitude 54°19'58"W).

For data collection, a questionnaire adapted from [14] was applied. The questionnaire consisted of 46 closed-ended questions, in which the response by beekeepers allowed the construction of a binary data matrix (1 or 0), and 4 open-ended questions (quantitative): honey productivity in kg per colony, number of colonies of *Apis mellifera*, age and experience in beekeeping activity in years. Each set of strictly related binary variables (closed-ended questions) that resulted in the construction of the indexes associated with the four beekeeping practices: equipment use, beekeeping management, harvesting and post-harvesting, and management and marketing can be seen in **Table 1**. As the study did not disclose any personal information about its participants, no approval was sought by an ethics committee.

2.2. Construction of apicultural indexes

The construction of the indexes occurred to facilitate the understanding of the set of attributes that determine each important aspect of the apicultural chain, as well as to be analyzed in association with the quantitative variables (open-ended questions) through the Principal Component Analysis.

The construction of the indexes was based on Miranda's method [15] for the determination of technological indexes. The index for each beekeeper j in apicultural practice g ($I_{g(j)}$) is given by:

$$I_{g(j)} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

where x_i represents the value [0 or 1] assumed by the i -th variable (with i varying from 1 to N) of the g -th beekeeping practice (with g varying from 1 to N beekeeping practices) in the j -th beekeeper (with j varying from 1 to N beekeepers). The n is the number of variables measured within the specified beekeeping practice.

Thus, for apicultural practice regarding the use of equipment, $g = 1$, $n = 12$, and $i = 1, \dots, 12$; for management, $g = 2$, $n = 19$, and $i = 1, \dots, 19$; for harvesting and post harvesting, $g = 3$, $n = 8$ and $i = 1, \dots, 8$ and for management and marketing, $g = 4$, $n = 7$ and $i = 1, \dots, 7$. Therefore, $n = \max \sum_{i=1}^n x_i$, therefore, $0 \leq I_{jg} \leq 1$.

The mean general index of beekeepers for beekeeping management practices (IM_g) is given by the sum of a beekeeping practice divided by the number of beekeepers and is calculated as:

$$IM_g = \frac{1}{N} \sum_{j=1}^N \sum_{i=1}^n \frac{x_i}{n} = \frac{1}{N} \sum_{j=1}^N I_{g(j)} \quad (2)$$

where N is the number of beekeepers measured ($N = 28$).

The general index for each beekeeper (IP_j), including all beekeeping management practices is given by:

$$IP_j = \frac{1}{g} \sum_{g=1}^g I_{g(j)} \quad (3)$$

where g is the number of beekeeping practices.

Beekeeping practices regarding the use of equipment ($n_1 = 12$)

1. Clothing (mask, hat, beekeeping suit, gloves and boots)	(1) use all	(0) some
2. Smoker (fuel)	(1) vegetable origin	(0) animal origin
3. Hive tool	(1) use	(0) not use
4. Bee brush	(1) use	(0) no use
5. Langstroth Hive	(1) standard	(0) not standard
6. Stainless steel equipment	(1) all	(0) some
7. Centrifuge	(1) electric	(0) manual
8. Decanter	(1) use	(0) not use
9. Uncapping table	(1) use	(0) not use
10. Strainer	(1) use	(0) not use
11. Decrystalizer	(1) use	(0) not use
12. Queen excluder	(1) use	(0) not use

Beekeeping practices regarding to management ($n_2 = 19$)

1. Food supply	(1) provide	(0) not provide
2. Queen replacement	(1) yes	(0) no
3. Honeycomb wax replacement	(1) annually	(0) no
4. Supersedure control	(1) use	(0) no
5. Colony division	(1) do	(0) do not
6. Comb management	(1) do	(0) do not
7. Opening of storage space	(1) yes	(0) no
8. Food storage	(1) deep super and honey super	(0) deep super only
9. Fight moths and ants	(1) yes	(0) no
10. Supplemental feeding	(1) provide	(0) not provide
11. Ventilation	(1) use	(0) not use
12. Shading	(1) natural	(0) artificial
13. Distance from water source	(1) < 500 m	(0) > 500 m
14. Uses more than one honey super per colony	(1) yes	(0) no
15. There is honeybee pasture	(1) yes	(0) no
16. Farthest honeybee pasture	(1) < 10 km	(0) > 10 km
17. Minimum proximity of other apiaries	(1) > 3 km	(0) < 3 km
18. Weekly frequency of visits to the apiary	(1) > 1 visit	(0) < 1 visit
19. Rent honeybee pasture	(1) yes	(0) no

Beekeeping practices regarding to honey harvest and post-harvest ($n_3 = 8$)

1. Smoke	(1) use	(0) not use
2. Comb cleaning	(1) yes	(0) no
3. Uncapping fork	(1) use	(0) not use

4. Honey processing	(1) honey house	(0) other
5. Honey super transport	(1) suitable	(0) no
6. Equipment hygiene	(1) yes	(0) no
7. Honey storage	(1) protected	(0) not protected
8. Containers for honey storage	(1) standard	(0) not standard
Beekeeping practices regarding to management and honey marketing ($n_4 = 7$)		
1. Contract for services	(1) yes	(0) no
2. Information on market trends	(1) yes	(0) no
3. Employees training	(1) yes	(0) no
4. Quality control	(1) yes	(0) no
5. Partnership: research	(1) yes	(0) no
6. Marketing	(1) use	(0) not use
7. Computing	(1) use	(0) not use

Table 1. Binary variables related to beekeeping practices.

The general index of the beekeeping system (IA), considering all beekeepers and all beekeeping practices, can be expressed as follows:

$$IA = \frac{1}{N} \sum_{j=1}^N IP_j = \frac{1}{g} \sum_{g=1}^g IM_g \quad (4)$$

2.3. Physicochemical analyses of honey

For the physicochemical analysis of honey, 28 honey samples from *Apis mellifera* were collected directly from beekeepers in the Western region of Paraná. Analyses of the physicochemical parameters of the honey samples were performed according to the Official Methods of Analysis, reported in detail in [16]. The evaluated parameters were: moisture (%), ash content (%), electrical conductivity ($\mu\text{S} \cdot \text{cm}^{-1}$), hydroxymethylfurfural content (HMF) ($\text{mg} \cdot \text{kg}^{-1}$), acidity ($\text{meq} \cdot \text{kg}^{-1}$), diastase activity (Goethe degrees), reducing sugars (%), apparent sucrose (%) and pH. The analyses were performed in triplicates from each parameter of the sample to obtain the data reported.

2.4. Statistical analyses

Minimum and maximum values, median, 5 and 95% percentiles, mean and standard mean error (SME), and Shapiro-Wilk normality test were calculated for the variables analyzed. Data from the questionnaire were analyzed using the technique of Principal Component Analysis (PCA) after normalization of the data, using Pearson $X'X$ correlation matrix. The multicollinearity diagnosis was performed for the correlation matrix [17]. Subsequently, another PCA was performed without transformation for the sample data related to the physicochemical honey analyses. The Kaiser-Guttman criterion was used to select the number of interpretable

axes in the PCA [12]. All statistical analyses were performed using the “R” software version 3.0.2 [18].

3. Results and discussion

Honey production of the beekeepers varied from 15.00 to 40.00 kg.colony⁻¹ (mean ± SME of 23.86 ± 1.16 kg.colony⁻¹) and 90% of beekeepers had honey production from 16.80 to 35.00 kg.colony⁻¹. The number of colonies kept by beekeepers varied from 12 to 430 (mean ± SME of 110 ± 19), and only one beekeeper had beekeeping as the main source of income. The age of beekeepers ranged from 26 to 77 years, while experience in the activity ranged from 6 to 50 years, with an approximate average of 22 years of experience in beekeeping (Table 2). Beekeeping in the Western region of Paraná is predominantly family friendly.

Camargo et al. [19] developed a Geographic Information System for beekeeping in the Western region of Paraná and found that 46% of the beekeepers had from 5 to 20 colonies, with honey production per colony no larger than 22.12 kg in the larger producer groups (i.e., they had larger areas of forest and smaller areas under agriculture). From our results, in general, it can be seen that the number of colonies kept by beekeepers increased, as well as there was a small increase in honey production per colony compared to 2009.

Possibly, the growth of the legal reserve area on these properties has been one of the factors responsible for such an increase in honey production, since we verified that no beekeepers pay rent to use an apiculture pasture and that good beekeeping practices related to management are not widely adopted (see results below). Brodschneider and Crailsheim [20] reported higher productivity of a colony is linked to the provision of balanced macronutrient nutrition. The increase in the area of forest near apiaries provides an increase in the diversity of

Indexes	Higher	Lower	Median	5%	95%	Mean ¹	SME
Beekeeping equipment	0.92	0.33	0.63	0.33	0.83	0.61	0.03
Beekeeping management practices	0.68	0.21	0.47	0.32	0.66	0.49	0.02
Management and marketing	0.57	0.29	0.29	0.29	0.43	0.33	0.01
Harvesting and post-harvesting techniques	0.90	0.44	0.74	0.64	0.90	0.75	0.02
General index for each beekeeper	0.72	0.34	0.54	0.42	0.68	0.55	0.02
Honey productivity in kg per colony	40.00	15.00	20.50	16.75	35.00	23.86	1.16
Number of colonies	430.00	12.00	75.00	21.75	302.00	110.32	19.39
Experience in beekeeping activity in years	50.00	6.00	19.00	7.35	40.00	21.93	2.22
Age	77.00	26.00	57.00	38.35	65.95	54.68	1.98

¹Mean obtained from 28 observations.

Table 2. Numerical summary of the survey on the adoption of beekeeping practices.

plants, which positively affects the nutrition of the honeybees and, consequently, increases the colony productivity [21].

The general index of beekeeping (IA) in the Western region of Paraná was 0.55. The general index for each beekeeper, which includes all beekeeping practices ranged from 0.34 to 0.72430 (mean \pm SME of 0.55 ± 0.02). Average rates for each beekeeping practice were: use of beekeeping equipment 0.61, management 0.49, harvesting and post-harvesting techniques 0.75, and management and marketing 0.33. There was a great variation of values for each index (see **Table 2**), which indicates the different adoption of practices in beekeeping.

The higher honey production is linked to the adoption of recommended beekeeping practices, especially those related to management (see **Figure 1**). However, only 50% of the beekeepers use more than half of the beekeeping practices recommended for management (median 0.48) (**Table 2**), with 50% of the beekeepers not adopting 50% of management recommendations regarding good beekeeping practices. Obviously, this can be an obstacle to production, because in addition to the honeybee flora, queen and old combs replacement, fighting diseases, and food supply are prime factors for the increase of honey production.

More than 50% of beekeepers adopt more than 74% of the recommendations of beekeeping practices regarding the harvesting and post-harvesting of honey (median = 0.74, **Table 2**). However, it represents the quality of the honey samples verified through the parameters (see **Table 3**), in which only some samples did not include the standards established by national and international legislation [22, 23].

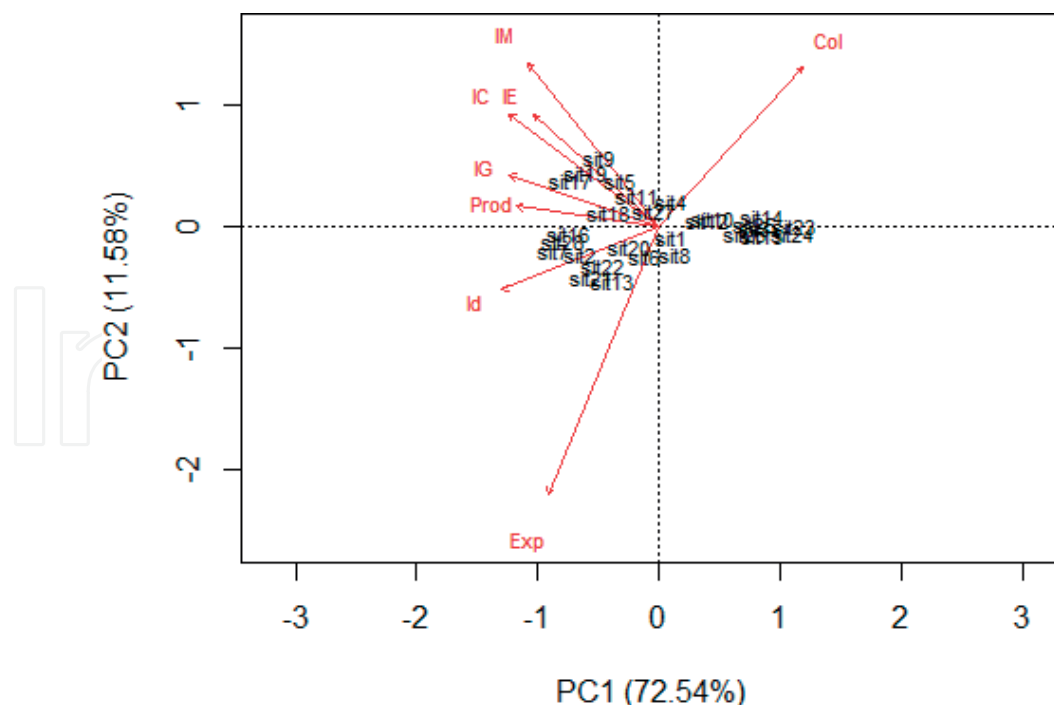


Figure 1. Ordering of the questionnaire data (normalized) in the first two main axes. Beekeeping equipment use (IE), beekeeping management practices (IM), harvesting and post-harvesting (IC), management and marketing (IG), honey productivity in kg per colony (Prod), number of colonies of *Apis mellifera* (Col), age (Id) and experience in beekeeping activity in years (Exp).

Parameters	Higher	Lower	Median	5%	95%	Mean ¹	SME
Acidity (mq.kg ⁻¹)	49.50	12.75	23.25	13.23	48.16	27.58	2.28
Reducing sugar (%)	90.40	64.42	74.08	66.01	84.92	74.47	1.03
Ash (%)	0.29	0.07	0.12	0.07	0.25	0.13	0.01
Electrical conductivity (μS.cm ⁻¹)	534.4	120.4	210.4	125.57	388.18	221.67	16.88
Diastase (° Goethe)	21.99	6.02	11.87	6.89	17.65	11.62	0.64
HMF* (mg.kg ⁻¹)	37.43	0.38	10.26	1.50	21.42	10.04	1.48
pH	4.48	3.44	3.94	3.62	4.30	3.94	0.05
Sucrose (%)	7.37	6.02	3.09	0.98	6.19	3.21	0.33
Moisture (%)	30.05	13.75	18.15	14.78	25.51	19.64	0.77

*Hydroxymethylfurfural.

¹Mean obtained from 28 observations.

Table 3. Numerical summary of physicochemical parameters of honey samples from *Apis mellifera* colonies, Paraná, Brazil.

The proportion of variance explained by the first two main components for the questionnaire data was 84.12% with the first axis explaining 72.54% and the second main axis 11.58% of the total variation, which in turn is satisfactory to explain most of the variation in PCA [12], see **Figure 1**.

Figure 1 represents a left-to-right gradient, starting with a similar group of the beekeepers (above the X-axis on the left) with higher values for honey productivity in kg per colony, management and marketing, harvesting and post-harvesting techniques, beekeeping equipment and management, which are also more correlated with each other. A second group of the beekeepers (below the X axis on the left) presented higher age and experience in beekeeping, which were variables with high negative correlation with the number of colonies and less positively correlated with honey productivity in kg per colony, management and marketing, harvesting and post-harvesting techniques, beekeeping equipment and management. A third group of beekeepers (to the right of the ordering on the X axis), very similar to each other, presented intermediate values in almost all measured variables.

Table 3 contains the results of the usual descriptive statistics of the eight physicochemical parameters of honey samples analyzed.

Honey acidity varied from 12.75 to 49.50 meq.kg⁻¹ (mean ± SME of 27.58 ± 2.28 meq.kg⁻¹), which is in accordance with the requirements of national and international regulations, which is, in general, no more than 50 meq.kg⁻¹ [22, 23]. The variation of acidity between the different samples can be attributed to floral origin, harvesting time of honey [8], or fermentation processes [24]. The free acidity of honey can be explained by the presence of organic acids in equilibrium with their corresponding lactones, or internal esters, and some inorganic ions, such as phosphate [25].

Honey is mainly composed of monosaccharides, such as glucose and fructose and disaccharide sucrose. The percentage of reducing sugars of the analyzed honey samples ranged from 65.03 to 90.40% (mean ± SME of 74.47 ± 1.03) and the average percentage of apparent sucrose

was 3.21, with a variation of 0.10 to 7.37% and an SME of 0.33. For the percentage of reducing sugars, the Brazilian standard establishes a minimum of 65% [22] and international regulation [23], in general, a minimum of 60%, and all the different analyzed samples was included in these specifications. However, 10% of samples had a percentage of apparent sucrose greater than that required by the legislation which was a maximum of 5% [22, 23].

Electrical conductivity and ash content are important parameters of honey quality [10]. Analyzed honey samples had ash content ranging from 0.07% to 0.29%, that is, below the maximum value of 0.60% [22, 23]. Electrical conductivity values of analyzed honey samples ranged from 120.4 $\mu\text{S}\cdot\text{cm}^{-1}$ to 534.4 $\mu\text{S}\cdot\text{cm}^{-1}$. Although there is no value recommended by Brazilian legislation [22] for electrical conductivity, the values obtained are within the scope of international regulation [23], which is desired to be smaller than 800 $\mu\text{S}\cdot\text{cm}^{-1}$. However, in honey samples analyzed from all regions of Brazil, it is very common to obtain values above this index for electrical conductivity.

The ash content is a direct measure of the inorganic residues present in honey sample after the carbonization, while the electrical conductivity measurements express all the organic and inorganic ionizable substances [10]. The electrical conductivity can be considered an important geographical marker for honey samples [26, 27] and ash content may be important in the evaluation of possible mineral contamination [10].

Hydroxymethylfurfural (HMF) and diastase activity are also indicators of honey quality. No sample exceeded the limits set for the HMF parameter, and 13% did not comply with national and international regulations for diastase activity: maximum HMF content of 40 $\text{mg}\cdot\text{kg}^{-1}$ and a minimum of 8 on the Goethe scale for diastase activity [22, 23]. HMF content of the analyzed honey samples ranged from 0.38 to 37.43 $\text{mg}\cdot\text{kg}^{-1}$, and diastase activity ranged from 6.02 to 21.99 on the Goethe scale, indicating that the honey sampled was high quality [10]. It was suggested that for a honey to be considered of high quality it is expected that it has high activity diastase and low content of HMF.

The knowledge of moisture in honey is useful to improve the conservation and storage practices of honey, since it prevents the growth of microorganisms [10]. For the analyzed honey samples, percentage of moisture varied from 13.75 to 30.05, with an average of 19.64% and SME of 0.77. Among the analyzed samples, 33% was not included in the requirements of national and international legislation, which establishes a maximum of 20% of moisture [22, 23]. In the 2008/2009 harvesting, [24] verified that 37.5% of honey samples from the Western region of Paraná presented values higher than 20% of moisture and considered that the responsible factors could be the premature harvesting of honey or the absorption of water from the environment during storage, because it is highly hygroscopic, or because of the amount of rainfall at the time when it was produced.

As honey moisture may be indicative of the mismanagement problem in the region, similar to what occurs in other regions of the country, [24] passed on this information to the regional cooperative beekeepers that provide them technical assistance, so that they are alerted and aware of the correct management. However, it is still apparent from our results that the measurements were not sufficient for the samples to reach the moisture requirements recommended by national and international legislation.

The PCA for the physicochemical parameters (normalized data) indicates that 71.92% of the variation in the data can be explained by the overall effect of the first two main axes. The first two axes have values corresponding to 53.14 and 18.78% of the total variance (**Figure 2**).

In **Figure 2**, PCA data for physicochemical parameters suggest similarities between honey samples, with the formation of only two groups: the first group of samples, to the right of the Y axis (PCA 1), was more similar for acidity, HMF, moisture, diastase, reducing sugars, apparent sucrose, and pH, and a second group, to the left of the Y axis (PCA 2), was more similar for electrical conductivity and ash. **Figure 2** presents a positive correlation between electrical conductivity and ash, acidity, and HMF, between diastase activity and moisture, as well as between reducing sugars, apparent sucrose, and pH.

Therefore, experience in beekeeping, beekeeper age, and a number of colonies kept on properties are not variables that are strongly associated positively with increased honey production. Another issue is that the analyzed honey samples were very similar for the physicochemical parameters, in addition to the ones recommended by national and international legislation, which is an indication of the honey quality of the western region of the State of Paraná, Brazil.

However, we are aware that our results have limitations, such as sample size. Even so, the analyses were efficient and can be a valid alternative for application in future studies. Therefore, new studies must be performed with the same technique of data analysis proposed here, however, with a larger sample size. This could reflect a more representative image of the reality of beekeeping, with the consequence of reducing the main bottlenecks in the honey production chain, aiming at maintaining quality and increasing honey production.

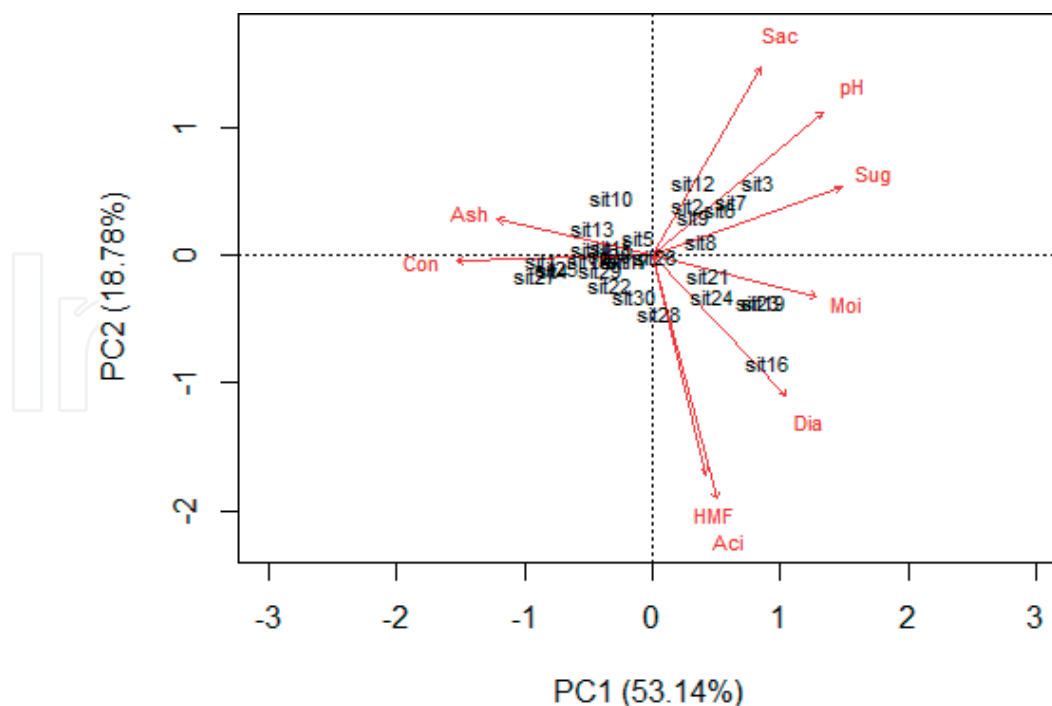


Figure 2. Ordering of the data referring to the physicochemical parameters (normalized) in the plane of the first two main axes. Moisture (Moi), ash content (Ash), electrical conductivity (Con), hydroxymethylfurfural content (HMF), acidity (Aci), diastase activity (Dia), reducing sugars (Sug), and apparent sucrose (Sac).

4. Conclusions

The construction of apicultural indexes and their associations with quantitative variables, using the multivariate technique of Principal Component Analysis was able to explain 84.12% of the total variation of the data in only two main axes and, therefore, proved to be efficient to draw a beekeeping profile, as well as for possible decision-making, with consequences for the future development of the activity. Statistical analysis indicated that the adoption of adequate beekeeping practices in the region, especially those related to the beekeepers' management and marketing of beekeeping products can provide a higher honey production in the region, especially due to its strong positive associations.

Acknowledgements

To CNPq (National Council for Scientific and Technological Development), process number 311663/2014-1 for the financial support, and CAPES (Coordination of Improvement of Higher Level Personnel) for the scholarship for the first author.

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