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## Research article

## Typology of Brazilian dairy farms based on vulnerability characteristics

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## ABSTRACT

Vulnerability has been a recurring theme in animal production research around the world, as it can lead to a series of outcomes, such as abandonment of the activity. Nevertheless, in Brazil, the fifth-largest milk producer in the world, studies assessing dairy farmers' vulnerabilities are scarce. Better understanding of dairy farm vulnerability may contribute to reducing the consequences of vulnerability. In view of these limitations, we sought to analyze the typology of dairy farms based on vulnerability characteristics. We applied on-site questionnaires to 128 dairy farmers located in Paraná State, Brazil. Structural, productive, and socioeconomic data were collected and subjected to factor analysis. Two vulnerability indicators were identified: F1, productive and economic indicator; and F2, feed self-sufficiency indicator. Hierarchical cluster analysis of factor scores revealed three groups of dairy farms: Group 1, highly vulnerable; Group 2, less vulnerable; and Group 3, non-vulnerable. Dairy farms with higher vulnerability represented most of the sample, followed by less vulnerable and non-vulnerable dairy farms. Our findings indicated that the productive and economic characteristics of farms contributed the most to explaining differences in vulnerability, followed by feed self-sufficiency characteristics. Social characteristics of farmers were not important in differentiating the analyzed sample. There was an interdependent relationship between vulnerability indicators, namely productive and economic characteristics and feed self-sufficiency.

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## Implications

We administered on-site questionnaires to collect data on production, socioeconomic characteristics of farmers, and farm vulnerability. The results present strategies to reduce vulnerability in dairy farms. For vulnerable farmers, we recommend actions to increase milk production volume, which can be achieved by participating in collective arrangements. Vulnerable farmers are also recommended to use technical assistance and improve production management. Another recommendation is to sell milk in market niches that value small-scale family production, based on social

appeals or organic and agroecological products. To reduce vulnerability problems related to feed self-sufficiency, we recommend that vulnerable dairy farmers implement grazing systems.

## Specification table

Subject	Livestock Farming Systems
Type of data	Table
How data were acquired	Data were collected on site (at the farm). The instrument for data collection was paper questionnaires.
Data format	Raw data

(continued on next page)

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Parameters for data collection	We administered questionnaires on-site, with 128 farmers to collect data about technical, structural, productive, and socioeconomic characteristics of farms and their operators, and variables related to farm vulnerability. Farmers were randomly selected from a list provided by technical advisors from agricultural cooperatives and extension agencies in Paraná State, Brazil.
Description of data collection	We collected data and information about technical, structural, productive, and socioeconomic characteristics of dairy farms and their operators and variables related to farm vulnerability. Variables were organized in an excel file.
Data source location	Institution: State University of Maringá City/Town/Region: Maringá, PR Country: Brazil Latitude and longitude (and GPS coordinates, if possible) for collected samples/data: 24°36'S 51°23'W
Data accessibility	The code to reproduce and analyze the data is deposited at Mendeley Data Repository Data identification number: <a href="https://data.mendeley.com/datasets/j94grxxkm5/4">https://data.mendeley.com/datasets/j94grxxkm5/4</a>
Related research article	None

## Introduction

Agricultural systems are regularly exposed to disturbances, prompting farmers to reorganize their operations. The responsiveness of production systems to such disturbances has been analyzed in vulnerability studies (Simelton et al., 2009; Mosnier et al., 2009). The concept of vulnerability is broad but typically encompasses the potential for loss in the face of negative events (Gallopín, 2006). Vulnerability also refers to risk, sensitivity, and fragility, which are inverse to resilience, adaptability, and stability (Hinkel, 2011). Callo-Concha and Ewert (2014) considered that the concept of vulnerability is directly related to sensitivity or the extent to which a system can absorb negative impacts without suffering damage during a given period. In this sense, the vulnerability of farm systems can be understood as the ability of farms to absorb perturbations without changing their functional structure—a buffering ability (Darnhofer, 2014).

Technical, institutional, and market transitions, combined with climate changes, have posed challenges to agricultural systems, creating unstable and volatile environments that necessitate constant reconfiguration for farms to maintain productivity and competitiveness (Darnhofer et al., 2008; Tendall et al., 2015; Martin et al., 2017; Bánkuti and Caldas, 2018). In this regard, dairy production has long been an important object of analysis in vulnerability studies because of its socioeconomic impact (Bouttes et al., 2019; Thorsøe et al., 2020). It is estimated that dairy production directly employs 895 million people worldwide; that is, 14% of the world's population directly depends on dairy farming for their living (FAO, 2021).

In Brazil, the fifth-largest milk-producing country, dairy production has economic and social functions, providing a monthly

income to more than 1.5 million families (IBGE, 2017). Moreover, dairy farming is particularly important for land occupation in areas not suitable for other agricultural activities because of geographical location, soil properties, topography, or other characteristics (Bánkuti and Caldas, 2018).

In Brazil, as well as in several other countries such as Canada, the United States of America, and China, institutional and market instability has led to a reduction in the number of dairy farms (IBGE, 2017; USDA, 2018; CDIC, 2020). The decrease in the number of Brazilian dairy farms began in the mid-90s and continues to this day (IBGE, 2017). The largest contraction was observed in southern Brazil, the region with the highest milk yield growth, which saw a 32% reduction in the number of registered dairies between 1996 and 2017. On the other hand, the remaining dairy systems have increased the number of animals and herd productivity (IBGE, 2017).

The diversity of Brazilian dairy farms and the changing scenarios of the dairy sector in the country seem to indicate the existence of a selection process that has culminated in the permanence or exit of dairy farms from the market. Vulnerable dairy farms are more likely to abandon the activity. Even if vulnerable farms do remain in business, they may be subject to adverse contexts and unfavorable conditions, failing to reach their full potential (van der Ploeg et al., 2012).

Starting from the premise that vulnerability refers to risk, sensitivity, and fragility, we sought to analyze the typology of dairy farms based on vulnerability characteristics. The results may guide the development of public and private strategies to reduce dairy farm vulnerability. Furthermore, a better understanding of the risk factors of vulnerability may help dairy farmers to anticipate decision-making, minimize negative effects, or take advantage of possible disturbances. We hypothesize that most of the farmers analyzed in our study have a high level of vulnerability, especially because of current market demands.

## Material and methods

This study was carried out in 2019 in five municipalities (Castro, Carambeí, Ponta Grossa, Palmeira, and Teixeira Soares) located in the Central-Eastern and Southeastern Mesoregions of Paraná State, Brazil. These regions are characterized by high herd productivity, with milk yields of about 10 000 L/cow/year (more than 40 L/cow/day). The milk yields of Castro, Carambeí, and Palmeira are above the national average (IBGE, 2017). Such excellent results are explained by the high genetic merit of herds, favorable climatic conditions, and wide adoption of feed production technologies (Bánkuti and Caldas, 2018).

Farm selection was performed from records of dairy farmers provided by technical advisors from agricultural cooperatives and extension agencies in Paraná State. Farmers were randomly selected from the lists and invited to participate in the study. At first contact, farmers were informed about the purpose of the study, methods of data collection, and type of information analyzed. We administered questionnaires on site to 128 farmers to collect data and information about technical, structural, productive, and socioeconomic characteristics of farms and their operators. Considering that the vulnerability concept is broad, the choice of these variables was based on a literature survey of studies assessing farm vulnerability and other factors that might influence the survival of dairy farms. Several studies have analyzed the survival of dairy systems according to concepts of competitiveness (Brito et al., 2015; Pigatto et al., 2020), sustainability (Lebacqz et al., 2015; Bánkuti et al., 2020), and resilience (Bouttes et al., 2019; Thorsøe et al., 2020). Variable selection was also influenced by studies discussing farm adaptation to current market demands

as a condition to remain in the activity (Bánkuti et al., 2020; Martinelli et al., 2022). The most analyzed variables were related to production volume, number of lactating cows, milk production area, milk quality, and road conditions (Brito et al., 2015; Zimpel et al., 2017; Pigatto et al., 2020). We also collected data to support the discussion and general characterization of the sample (Table 1).

Development of vulnerability indicators

Vulnerability indicators were generated from 25 variables (Table 1) using factor analysis. Factor analysis is an interdependence technique that reduces a large set of variables into factors, also referred to as indicators (Bánkuti et al., 2020). The factor analysis model used in this study is expressed by Eq. (1):

$$\begin{aligned}
 X_1 &= a_{11} \times F_1 + a_{12} \times F_2 + \dots + a_{1m} \times F_m + e_p \\
 X_2 &= a_{21} \times F_1 + a_{22} \times F_2 + \dots + a_{2m} \times F_m + e_p \\
 &\vdots \\
 X_p &= a_{p1} \times F_1 + a_{p2} \times F_2 + \dots + a_{pm} \times F_m + e_p
 \end{aligned}
 \tag{1}$$

where  $X_p$  is the  $p$ -th score of the standardized variable ( $P = 1, 2, \dots, m$ ),  $F_m$  is the extracted factor,  $a_{pm}$  is the factor loading, and  $e_p$  is the error.

Table 1 Variables used in this study.

Variable	Type <sup>a</sup>	Statistical analysis
V1. Number of family members (parents/partners and children)	Numerical	DA/FA
V2. Number of family members living on the farm	Numerical	DA/FA
V3. Duration of family residency on the farm (years)	Numerical	DA
V4. Farm size (ha)	Numerical	DA/FA
V5. Leased area (ha)	Numerical	DA/FA
V6. Gross monthly income (R\$)	Numerical	DA/FA
V7. Net monthly income (R\$)	Numerical	DA/FA
V8. Dairy farming experience (years)	Numerical	DA/FA
V9. Daily milk production (L/day)	Numerical	DA/FA
V10. Duration of partnership with current buyer (year)	Numerical	DA
V11. Milk price (R\$/L)	Numerical	DA/FA
V12. Somatic cell count (cells/mL)	Numerical	DA/FA
V13. Total bacterial count (colony-forming units/mL)	Numerical	DA/FA
V14. Milk fat content (%)	Numerical	DA/FA
V15. Milk protein content (%)	Numerical	DA/FA
V16. Daily milk production per cow (L/cow)	Numerical	DA/FA
V17. Number of lactating cows	Numerical	DA/FA
V18. Herd size	Numerical	DA/FA
V19. Age at first calving (months)	Numerical	DA/FA
V20. Calving interval (months)	Numerical	DA/FA
V21. Lactation duration (days)	Numerical	DA/FA
V22. Road quality	Ordinal (1, very poor; 2, poor; 3, good; 4, excellent)	FA
V23. Uses outsourced equipment for forage production	Ordinal (1, yes; 2, no)	DA/FA
V24. Sufficient silage production	Ordinal (0, does not use; 1, no; 2, yes)	DA/FA
V25. Buys silage	Ordinal (0, does not use; 1, yes; 2, no)	DA/FA
V26. Buys haylage	Ordinal (0, does not use; 1, yes; 2, no)	DA/FA
V27. Buys hay	Ordinal (0, does not use; 1, yes; 2, no)	DA/FA

DA, descriptive analysis; FA, factor analysis.

All variables related to vulnerability were used in factor analysis.

<sup>a</sup> Ordinal variables are logically ordered (the highest value indicates the least vulnerable practice).

The factor score of each dairy farm was estimated by multiplying the standardized variable score by the corresponding factor score coefficient (Eq. (2)):

$$\begin{aligned}
 F_1 &= d_{11} \times X_1 + d_{12} \times X_2 + \dots + d_{1j} \times X_{jp} \\
 F_2 &= d_{21} \times X_1 + d_{22} \times X_2 + \dots + d_{2j} \times X_{jp} \\
 &\vdots \\
 F_j &= d_{j1} \times X_1 + d_{j2} \times X_2 + \dots + d_{jp} \times X_{jp}
 \end{aligned}
 \tag{2}$$

where  $F_j$  is the  $j$ -th extracted factor,  $d_{jp}$  the factor score coefficient, and  $p$  the number of variables (Hair et al., 2009).

For factor analysis, data were extracted by principal component analysis with varimax rotation, Kaiser–Meyer–Olkin (KMO) normalization, and Bartlett’s test of sphericity (Hair et al., 2009). Variables with factor loadings of less than |0.5| were excluded, and factors with eigenvalues equal to or greater than 1.0 were retained, according to the Kaiser criterion (Hair et al., 2009). Factor scores were saved as regression scores and subjected to analysis of variance, mean tests, and hierarchical cluster analysis (Field, 2009; Bánkuti et al., 2020). In this study, factor scores are considered to indicate the level of vulnerability of the analyzed dairy farms. This procedure has been widely applied in other studies (Bánkuti et al., 2020; Indrawan et al., 2020; Lima et al., 2020).

Defining groups of farms with different degrees of vulnerability

Factor scores were used as input variables for the categorization of dairy farms into vulnerability groups by hierarchical cluster analysis (Bánkuti et al., 2020). Hierarchical cluster analysis is an interdependence technique that groups cases in a manner that provides the greatest internal similarity (between cases of the same group) and the least external similarity (between cases of different groups) (Hair et al., 2009). The hierarchical clustering model is described in Eq. (3).

$$d[k, (ij)] = \max[d(k, i), d(k, j)]
 \tag{3}$$

This agglomerative algorithm calculates the shortest distance between elements  $i$  and  $j$  using the distance matrix  $d_{ij}$  (Hair et al., 2009). Clustering was performed using complete linkage and the squared Euclidean distance (Hair et al., 2009). The number of retained groups was defined by dendrogram analysis using the maximum Euclidean distance between groups, and the degree of vulnerability of dairy farms was assessed by comparing mean factor scores across groups. In this step, numerical data were subjected to analysis of variance and mean tests. Several studies used this procedure to analyze animal production systems (Indrawan and Daryanto, 2020; de Oliveira Sidinei et al., 2021).

For the selection of the most appropriate mean test, factor scores were analyzed by the Kolmogorov–Smirnov, Shapiro–Wilk, and Levene’s tests. As the data were found to be non-normally distributed, the non-parametric Mann–Whitney  $U$ -test ( $P < 0.05$ ) was used for mean comparisons between groups (Field, 2009).

Ordinal data (Table 1) were subjected to crosstab analysis and Pearson’s chi-squared test. Cross tabulation generates tables describing the relationship between variables. Chi-square statistics are the most used measure of statistical significance for crosstabs and can be used to assess whether two variables are independent.

Characteristics of dairy farm groups with different degrees of vulnerability

Factor analysis provided a more objective assessment of dairy farm groups according to vulnerability indicators. However, the generated indicators do not have a single unit of measurement, precluding a dimensional comparison of each variable in a more

applied context. It is difficult to understand, for instance, how distant one group is from the other in terms of production volume or net monthly income. Therefore, we opted to examine the characteristics of farm groups using the variables selected for the generation of vulnerability indicators. With this procedure, it was possible to gain a more applied understanding of the dimension of differences between farm groups (de Oliveira Sidinei et al., 2021). As in the previous step, data were verified for normality. Non-normality was indicated, and the Mann-Whitney U-test ( $P < 0.05$ ) was used for mean comparisons (Field, 2009).

## Results

### General characteristics of the sample

The evaluated dairy farms had a small number of workers and were operated by farmers with good experience in dairy farming. The mean number of family members living on the farm was  $3.62 \pm 2.37$  people, ranging from 0.0 to 12.0 people. Individuals had lived on the farm for on average  $20.32 \pm 13.08$  years, with the minimum time being 1.0 year and the maximum 65.0 years. As for farm operators, they had on average  $16.71 \pm 11.50$  years of experience in dairy farming, ranging from 2.0 to 45.0 years. Dairy farms had a mean daily milk production of  $2\ 914.02 \pm 7\ 318.85$  L, with a minimum production of 60.0 L and a maximum production of 72 000 L. The mean price of 1 L of milk was R\$1.42  $\pm$  0.46, ranging from R\$1.08 to R\$1.70. Farms housed on average  $148.78 \pm 360.89$  lactating cows, with a minimum number of 4.0 lactating cows and a maximum number of 2 500 lactating cows. The mean herd size was  $228.48 \pm 481.68$  cows, ranging from 21.0 to 3 300 animals, with a mean milk production per cow of  $25.65 \pm 8.86$  L/day and a range of 10.0–45.0 L/cow/day. The mean net monthly income was R\$33 404.72  $\pm$  R\$155 563.92, varying between R \$200.00 and R\$1 700 000.00.

### Groups of farms with different vulnerability degrees

Factor analysis was initially performed with 25 variables. However, 17 were excluded for having low factor loadings (Hair et al., 2009). This result indicates that 17 variables related to farmers' social characteristics, milk quality parameters, cow reproduction efficiency, road quality, and other variables did not explain the variability in the cases analyzed. The best model fit was obtained with seven variables related to milk production volume, income, number of lactating cows, and variables associated with feed production capacity (Table 2). For this model, KMO test and Bartlett's sphericity test results were 0.74 and 0.00, respectively, demonstrating the adequacy of variables for factor analysis (Hair et al., 2009).

Factor analysis generated two factors/vulnerability indicators, F1 (37.8% of variance) and F2 (30.0% of variance), which together explained 67.8% of the total variance in the dataset. Factor 1 was defined by the variables of daily milk production, net monthly

**Table 2**  
Variables that defined the vulnerability indicators.

Variable	F1	F2
Daily milk production (L/day)	0.935	0.243
Net monthly income (R\$)	0.903	0.141
Number of lactating cows	0.880	0.209
Buys silage	0.083	0.847
Sufficient silage production	0.089	0.813
Buys hay	0.240	0.586
Buys haylage	0.320	0.511

F1, productive and economic indicator; F2, feed self-sufficiency indicator.

income, and number of lactating cows (Table 2). Thus, F1 was named productive and economic indicator of vulnerability. The greater variance of F1 indicates that productive and economic characteristics associated with production scale in dairy systems are the most important to discriminate the analyzed cases and, therefore, are the ones that contribute the most to explaining dairy farm vulnerability in this study. Factor 2 was formed by variables related to feed production capacity, including silage purchase, sufficient silage production, haylage purchase, and hay purchase (Table 2). Based on these characteristics, F2 was called feed self-sufficiency indicator of vulnerability.

Factors scores of F1 and F2 (indicators of vulnerability) were used for the hierarchical clustering of dairy farms (Toro-Mujica et al., 2015; Bánkuti et al., 2020). Cluster analysis revealed that one of the dairy farms had markedly different characteristics from the others, affecting group consistency. Thus, the case was classified as an outlier and removed from the analysis. Three groups were defined: group 1 with 106 farms (84.1%), group 2 with 15 farms (11.9%), and group 3 with five farms (4.0%).

The mean test demonstrated that group 1 had negative scores on F1 ( $-0.31 \pm 0.02$ ) and F2 ( $-0.11 \pm 0.09$ ), which were significantly lower than those of the other groups ( $P < 0.05$ ). Therefore, group 1 was classified as being highly vulnerable (**HV**) (Table 3). This result supports the hypotheses defined in this study. The second group had superior scores on F1 ( $0.87 \pm 0.07$ ) and F2 ( $0.70 \pm 0.17$ ) compared with highly vulnerable farms ( $P < 0.05$ ) and was therefore classified as less vulnerable (**LV**). The third group showed positive scores on F1 ( $4.07 \pm 0.78$ ) and F2 ( $0.35 \pm 0.17$ ) and had the highest score on F1 ( $P < 0.05$ ). Thus, this group was characterized as non-vulnerable (**NV**) (Table 3).

### Vulnerability and the productive and economic characteristics of farms

Daily milk production differed between groups ( $P < 0.05$ ). Highly vulnerable farms produced the lowest volume of milk,  $936.13 \pm 715.95$  L/day. Less vulnerable farms produced  $7\ 390.00 \pm 1\ 357.28$  L/day, and non-vulnerable farms produced  $17\ 600.00 \pm 5\ 079.37$  L/day (Table 4). Highly vulnerable farms had a mean number of lactating cows of  $43.14 \pm 34.62$ ; less vulnerable farms,  $352.80 \pm 210.66$ ; and non-vulnerable farms,  $1\ 306.00 \pm 638.89$  ( $P < 0.05$ ). The net monthly income was R\$8 107.54  $\pm$  R\$5 886.57 in highly vulnerable farms, R\$51 266.66  $\pm$  R\$50 190.04 in less vulnerable farms, and R\$182 800.00  $\pm$  R\$139 746.91 in non-vulnerable farms. Differences were observed between groups ( $P < 0.05$ ) (Table 4).

### Vulnerability and the feed self-sufficiency of farms

Analysis of variables composing the feed self-sufficiency indicator showed that 28.3% of highly vulnerable farms did not use hay. A large fraction of highly vulnerable farms (42.5%) used hay but depended on its purchase, and 29.2% used hay produced on the farm. On-farm hay production was more frequent among less vulnerable farms (60.0%) and non-vulnerable farms (66.7%), with significant differences between groups ( $P < 0.05$ ) (Table 5).

Highly vulnerable farms also had the lowest use of haylage in dairy cow diets. Nearly half of the highly vulnerable farms (41.5%) did not use haylage and many (32.1%) were highly dependent on purchasing haylage, indicating high vulnerability of feed self-sufficiency for farmers of the highly vulnerable group. Differences in haylage use were observed between groups ( $P < 0.05$ ) (Table 5).

All farms from less vulnerable and non-vulnerable groups used hay, and the majority produced hay on the farm (60.0% of less vulnerable farms and 66.7% of non-vulnerable farms). All less vulnerable and non-vulnerable farms used haylage for cow nutrition. Less

**Table 3**  
Vulnerability indicators between groups of dairy cattle farms.

Indicator	Group	Mean	Standard error	P-value
F1 – Productive and economic	HV	-0.31 <sup>c</sup> ± 0.24	0.02	<0.001
	LV	0.87 <sup>b</sup> ± 0.29	0.07	
	NV	4.07 <sup>a</sup> ± 1.75	0.78	
F2 – Feed self-sufficiency	HV	-0.11 <sup>b</sup> ± 1.01	0.09	0.009
	LV	0.70 <sup>a</sup> ± 0.67	0.17	
	NV	0.35 <sup>a</sup> ± 0.38	0.17	

HV, highly vulnerable dairy farms; LV, less vulnerable dairy farms; NV, non-vulnerable dairy farms.

<sup>a,b,c</sup> Values followed by different letters are significantly different ( $P < 0.05$ ) by the Mann–Whitney  $U$ -test ( $P < 0.05$ ).

**Table 4**  
Productive and economic characteristics of dairy cattle farms groups.

Variable	Group	Mean*	Standard error	P-value
Daily milk production (L/day)	HV	936.13 <sup>c</sup> ± 715.95	69.54	<0.001
	LV	7 390.00 <sup>b</sup> ± 1 357.28	350.45	
	NV	17 600.00 <sup>a</sup> ± 5 079.37	2 271.56	
Number of lactating cows	HV	43.14 <sup>c</sup> ± 34.62	3.36	<0.001
	LV	352.80 <sup>b</sup> ± 210.66	54.39	
	NV	1 306.00 <sup>a</sup> ± 638.89	285.72	
Net monthly income (R\$)	HV	8 107.54 <sup>c</sup> ± 5 886.57	571.75	<0.001
	LV	51 266.66 <sup>b</sup> ± 20 190.04	5 213.04	
	NV	182 800.00 <sup>a</sup> ± 139 764.91	62 496.72	

HV, highly vulnerable dairy farms; LV, less vulnerable dairy farms; NV, non-vulnerable dairy farms.

<sup>a,b,c</sup> Values followed by different letters are significantly different ( $P < 0.05$ ) by the Mann–Whitney  $U$ -test ( $P < 0.05$ ).

**Table 5**  
Observed frequency, expected frequency, and adjusted residuals of hay and haylage use in dairy cattle farms groups.

Variable	Frequency	N (%)		
		HV	LV	NV
Hay not used	Observed frequency	30 (28.3%)	0.0 (0.0%)	0.0 (0.0%)
	Expected frequency	25	3.5	1.4
	Adjusted residuals	2.8	-2.3	-1.4
Hay purchased	Observed frequency	45 (42.5%)	6 (40.0%)	2 (33.3%)
	Expected frequency	44.2	6.3	2.5
	Adjusted residuals	0.4	-0.1	-0.4
Hay produced on farm	Observed frequency	31 (29.2%)	9 (60.0%)	4 (66.7%)
	Expected frequency	36.7	5.2	2.1
	Adjusted residuals	-2.9	2.2	1.7
Total		106 (100%)	15 (100%)	6 (100%)
Haylage not used	Observed frequency	44 (41.5%)	0 (0.0%)	0 (0.0%)
	Expected frequency	36.7	5.2	2.1
	Adjusted residuals	3.7	-3.0	-1.8
Haylage purchased	Observed frequency	34 (32.1%)	5 (33.3%)	2 (33.3%)
	Expected frequency	34.2	4.8	1.9
	Adjusted residuals	-0.1	0.1	0.1
Haylage produced on farm	Observed frequency	28 (26.4%)	10 (66.7%)	4 (66.7%)
	Expected frequency	35.1	5.0	2.0
	Adjusted residuals	-3.6	2.9	1.8
Total		106 (100%)	15 (100%)	6 (100%)

HV, highly vulnerable dairy farms; LV, less vulnerable dairy farms; NV, non-vulnerable dairy farms.

Hay and haylage use, Pearson's chi-squared test ( $P < 0.005$ ).

vulnerable and non-vulnerable farms were similar and more self-sufficient than highly vulnerable farms. The percentage of farms producing haylage was 26.4%, 66.7%, and 66.7% in highly vulnerable, less vulnerable, and non-vulnerable groups, respectively. Highly vulnerable farms differed from the other two groups of farms ( $P < 0.05$ ) (Table 5).

Highly vulnerable farms had the lowest silage production capacity. The frequency of farms that bought silage was 50.9% in highly vulnerable farms, 20.0% in less vulnerable farms, and 16.7% in non-vulnerable farms ( $P < 0.05$ ) (Table 6).

Non-vulnerable farms had the highest self-sufficiency in silage production and supply, followed by less vulnerable and highly vulnerable farms ( $P < 0.05$ ). Year-round supply of silage was observed

in 52.8% of highly vulnerable farms, 93.3% of less vulnerable farms, and 100% of non-vulnerable farms (Table 6).

**Author's points of view**

The main finding of this study was the interdependent relationship between productive, economic, and feed self-sufficiency characteristics of dairy farms. Productive and economic characteristics related to scale of production were the most important in differentiating dairy farms. The characteristics related to feed self-production also seemed to be determinant in assessing the vulnerability of dairy farmers in this study. By contrast, social variables of rural farmers and family members were not relevant for vulnera-

**Table 6**  
Observed frequency, expected frequency, and adjusted residuals of silage use in dairy cattle farms groups.

Variable	Frequency	N (%)		
		HV	LV	NV
Silage purchased	Observed frequency	54 (50.9%)	3 (20.0%)	1 (16.7%)
	Expected frequency	48.4	6.9	2.7
	Adjusted residuals	2.7	-2.1	-1.5
Silage produced on farm	Observed frequency	52 (49.1%)	12 (80.0%)	5 (83.3%)
	Expected frequency	57.6	8.1	3.3
	Adjusted residuals	-2.7	2.1	1.5
Total		106 (100%)	15 (100%)	6 (100%)
Insufficient silage production	Observed frequency	50 (47.2%)	1 (6.7%)	0 (0.0%)
	Expected frequency	42.6	6.0	2.4
	Adjusted residuals	3.6	-2.8	-2.1
Sufficient silage production	Observed frequency	56 (52.8%)	14 (93.3%)	6 (100.0%)
	Expected frequency	63.4	9.0	3.6
	Adjusted residuals	-3.6	2.8	2.1
Total		106 (100%)	15 (100%)	6 (100%)

HV, highly vulnerable dairy farms; LV, less vulnerable dairy farms; NV, non-vulnerable dairy farms.  
Pearson's chi-squared test ( $P < 0.005$ ).

bility assessment. Furthermore, we noted that, in the analyzed sample, most farmers had a high degree of vulnerability.

Our results may guide the development of private and public strategies for dairy farmers. Highly vulnerable farms are recommended to take urgent action to increase milk production and improve net income, generating financial resources that can be reinvested in milk production. As possible strategies to increase milk production, it is suggested participation in collective partnerships, such as dairy cooperatives, combined with good technical support and adoption of system management practices. An alternative strategy would be to focus on new market niches that value small-scale family farming or organic/agroecological production methods. To minimize the negative impact of their low self-sufficiency in feed production, highly vulnerable dairy farmers should consider implementing grazing systems. Considering less vulnerable dairy farms are recommended to participate in dairy cooperatives, upscale milk production, and invest in feed production. By doing so, less vulnerable farms can become non-vulnerable to current market demands. Of note, less vulnerable and non-vulnerable farms differed mainly in economic variables.

Non-vulnerable farms can be considered a reference group, and their production model should be followed by other dairy farms in Paraná and Brazil. However, this can only be achieved with public and private support. Public efforts should be directed toward technical assistance, agricultural outreach, and subsidies. Private actions are suggested to focus on the promotion of partnerships and associations between rural producers, participation in cooperatives, and establishment of contracts between farmers and processing industries.

The results of the current study agree with current knowledge on the topic. As shown by productive and economic variables (represented by F1), highly vulnerable farms comprised mainly small-scale farms, less vulnerable farms were medium scale, and non-vulnerable farms were large scale. This scenario highly represents the reality of milk production in the analyzed region and Brazil (IBGE, 2017). It is important to mention that, although highly vulnerable farms had the worst productive and economic indicators, their herd size and daily milk production were higher than those of most dairy farms in other regions of Paraná State and Brazil (IBGE, 2017).

The higher productive performance of highly vulnerable farms compared with farms across Paraná State and Brazil can be attributed to the characteristics of farms in the analyzed region. As previously reported, Paraná State holds one of the major dairy basins in the country. The municipalities of Castro and Carambeí, located

in the analyzed region, are the largest national milk producers. Together, both municipalities accounted for 11% of the total production in Paraná State in 2018 (IBGE, 2020). Bánkuti and Caldas (2018) argued that the good performance of dairy farms in southern Paraná is due to institutional and market factors, in addition to high technological level, large production scale, and limited alternatives for land use. Siqueira et al. (2021) demonstrated the importance of local cooperatives, farmers' network, and universities to the adaptability of dairy farmers to current institutional and market characteristics. Thus, although less vulnerable farms were classified as having a low vulnerability, it can be said that they exhibit good economic performance compared with the majority of Brazilian dairy farms (IBGE, 2017).

Non-vulnerable farms were better adapted to institutional and market demands of the past years in Brazil. As reported by Bánkuti and Caldas (2018), the importance of milk production in southern Paraná has increased over the past years, boosted by good management practices, technology use, and participation in collective arrangements. In the 1990s, milk production was replaced with crop production in the northern region of Paraná State, stimulating family dairy farming in the southern region (Bánkuti and Caldas, 2018). Technology use improved milk production, contributed to the development of the agro-industrial milk sector, and enhanced transportation logistics in the region. This scenario allowed farmers to invest in milk production, further enhancing production scale and milk quality, as observed in non-vulnerable farms.

Considering net income, no official data are available for dairy farms in Paraná or Brazil, hindering comparison. Highly vulnerable farms had a net monthly income of R\$ 8 107.54, equivalent to just over eight Brazilian minimum wages, which is a reasonable income for a family of four in the country. As previously mentioned, the sample of family farms was defined by four members. Less vulnerable farms earned on average more than 51 Brazilian minimum wages per month, considerably higher than the average income of the Brazilian population. The net monthly income of non-vulnerable farms was equivalent to 183 Brazilian minimum wages. Such a high income is evidence of the professionalization of non-vulnerable farms compared with farms in Paraná State and Brazil, as discussed by Bánkuti and Caldas (2018).

Our findings indicated that the productive and economic characteristics of farms contributed the most to explaining differences in vulnerability, followed by feed self-sufficiency characteristics. Social characteristics of farmers were not important in differentiating the analyzed sample. There was an interdependent relationship

between vulnerability indicators, namely productive and economic characteristics and feed self-sufficiency.

There are some limitations to this study, including the impossibility of extrapolating the results. This is mainly due to the small number of farms analyzed. However, we believe that the findings well represented the cases. The second limitation stems from the fact that data collection was performed at a single time point, not allowing for temporal analysis.

The data from this survey can be used by researchers, dairy companies, technical assistance agencies, rural outreach programs, milk production cooperatives, and government agencies that promote agricultural production. The information can be used in several ways, for instance, to analyze issues related to production, profitability, and nutritional strategies of dairy systems. Furthermore, the socioeconomic issues of rural farmers and their families can be assessed. Future studies should analyze vulnerability issues over time and other aspects related to vulnerability, such as environmental sustainability and climate change.

### Ethics approval

This study was approved by the Human Research Ethics Standing Committee of the State University of Maringá, Paraná, Brazil (protocol no. 2.396.173).

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### Declaration of interest

None.

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