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Synergies Between Climate Instability And Milk Production In Ceará State, Brazil

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Abstract:
This research has the following objectives: a) To evaluate the descriptive statistics of climatic variables and those that impacted the value of milk production in the state of Ceará between 1997 and 2020; b) To create Temporal Instability Indices (INST) and index of milk production (IMPR) that capture synergies between climatic variables and milk production in the municipalities of Ceará; c) To hierarchize the climatic regions created by FUNCEME; d) To assess the relationship between IMPR and INST in the state and in the climatic regions. The data used was taken from the Municipal Livestock Production (PPM), the IBGE Statistical Yearbooks and the National Oceanic and Atmospheric Administration (NOAA). The methodological procedures include estimating the descriptive statistics of the variables that define milk production in the municipalities of Ceará, as well as rainfall and temperatures. Climate instability and the variables that define milk production in the period are estimated. Factor analysis was used to calculate IMPR and INST. Pearson's correlation coefficient was used to assess the relationship between these indices. The results showed good statistical fit. Based on the IMPR, the climatic regions are grouped into six, which express different average milk production indicators. With regard to INST, the research results grouped the eight climatic regions into four, which express varying aggregate instabilities. The results confirmed Markowitz's expectation that higher average production levels are associated with greater instability and therefore greater risk.
Key Word: *Climate instabilities; Caatinga biome; Extreme weather events.*

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I. Introduction

World milk production grew from approximately 498.65 billion liters in 2016 to 532.30 billion liters in 2020, representing an increase of 6.3%. In 2020, the largest producers were the European Union, with 156.70 billion liters, and the United States, with 100.48 billion liters (USDA/FARM REPORTS, 2020). In Brazil, production increased from 30.72 billion liters in 2010 to 35.32 billion liters in 2020, but decreased to 34.61 billion liters in 2022 (IBGE, 2022).

In the Northeast, production increased from 4.92 billion liters (13.93% of the national total) in 2010 to 5.72 billion liters (16.54% of the national total) in 2022. The northeastern states with the highest production were Bahia (22.33%), Pernambuco (20.6%) and Ceará (18.58%). Brazil has 15,740,153 milked cows, of which 3,879,613 (24.65%) are located in the Northeast region, with Bahia standing out with 967,254 cows (24.93%), Ceará with 659,039 (16.99%) and Pernambuco with 542,755 (13.99%). In Ceará, the municipalities with the most milked cows are Morada Nova (40,020), Iguatu (24,840) and Quixeramobim (20,325).

Milk production in the northeast of Brazil, especially in the semi-arid region, faces major challenges due to climate instability, such as variations in rainfall and temperature fluctuations. These climatic conditions directly influence the production and productivity of lactating cows, affecting animal health and altering the production environment. The availability of water is a crucial factor, as its scarcity can limit milk production. In addition, extreme weather events, such as droughts or excessive rainfall, compromise forage production and increase the incidence of disease, affecting the sustainability of dairy farming in the region (Lemos, 2020; Curi, 2020; Lemos et al., 2023; Galvão Júnior et al., 2015; Veiga, 2023).

Climate variability in the semi-arid region is a significant challenge for dairy farmers, resulting in one of the lowest milk yields in Brazil. A study by Lemos et al. (2022) introduced the Instability Index (INST) to evaluate milk production in different climatic conditions in municipalities in Ceará, showing that milk production is lower in periods of drought compared to normal and rainy periods. In addition, the division of Ceará into eight climatic regions by FUNCEME highlights the heterogeneity of climatic conditions in the region, underlining the complexity and importance of considering climatic variability when planning and managing milk production in the Brazilian Northeast (Paiva, 2018; Lemos et al., 2023). In a previous study by Salviano (2021), it was shown that these regions present heterogeneity in the production of rainfed crops.

This study sought to assess whether this heterogeneity also manifests itself in milk production. Thus, this research seeks to answer the following questions: how do climatic variables interact with those that define milk production in the state and how do they affect milk production?

To answer this question this research has the following objectives: a) To evaluate the descriptive statistics of climatic variables and those that impacted the value of milk production in the state of Ceará between 1997 and 2020; b) To create Temporal Instability Indices (INST) and index of milk production (IMPR) that capture synergies between climatic variables and milk production in the municipalities of Ceará; c) To hierarchize the climatic regions created by FUNCEME; d) To assess the relationship between IMPR and INST in the state and in the climatic regions.

II. Theoretical Background

The state of Ceará, with its strategic geographical location and diversified economy, has a history of growth in both the agricultural and livestock sectors. Characterized by a semi-arid climate and the predominant biome of the caatinga, Ceará faces challenges due to the absence of perennial rivers and the severity of droughts (Paiva, 2018). Livestock farming began in the colonial period, with the introduction of cattle by the Portuguese, initially focused on meat and leather production, but later incorporating milk production. This sector played a crucial role in the settlement of the region, transforming Ceará into the "Civilization of Leather" (Oliveira, 2021).

In the 18th century, the jerky trade drove economic growth, leading to the development of cities such as Aracati and Sobral (Girão, 1989). In the 19th century, dairy farming continued to develop, despite adverse climatic conditions. In the 20th century, the modernization of dairy farming began with government policies that encouraged the construction of dams and rural credit programs, improving the conditions for raising dairy cattle. In the 1970s and 1980s, the introduction of more productive breeds and artificial insemination technologies increased milk production.

Recently, technical assistance programs and the creation of producer associations have strengthened the sector, promoting sustainable management practices and advanced technologies (Vilela, 2016; Rocha, 2018). Studies carried out by Paiva, Lemos and Campos in 2022 confirm the influence of rainfall conditions and prices on milk production, highlighting the importance of genetic improvements and management practices for sustainability. In 2022, milk production in Ceará grew by 10.7%, totaling 1.1 billion liters, reflecting promising advances for the sector (IBGE).

Ceará is among the main milk producers in the Northeast, with the sector demonstrating its relevance to the state economy. In regions such as the Jaguaribe Valley, producers are adopting innovative practices, such as the dense planting of fodder palm, a highly efficient crop in terms of water use and nutritionally rich for feeding dairy cattle. These practices are essential for increasing productivity in a semi-arid environment.

According to Matallo Júnior (2001), dry and semi-dry climate areas cover one third of the earth's surface and are home to one sixth of the world's population, spread across all continents. In these regions, rainfall is scarce, irregular and occurs over short periods, and is less than the potential evapotranspiration. The Brazilian semi-arid is one of these regions, characterized by high rainfall variability, high temperatures with little variation and low relative humidity. The fluctuations between periods of drought and heavy rain significantly impact agriculture and livestock, highlighting the need for efficient management practices to optimize production (Brito et al., 2012; Bezerra, 2022; Lemos, 2020; Salviano, 2021; Praxedes, 2021).

Climate fluctuations have a strong influence on agriculture. Silva et al. (2019) observed that the hottest months cause stress in dairy cattle, resulting in losses in the quality and quantity of food provided, a reduction in food consumption and a drop in milk production. In addition, soil quality in the semi-arid region is a challenge for agriculture. Most soils have low production capacity due to fertility, depth, drainage or salinity problems. Much of the region is on a crystalline geological base, where the parent rock is close to the surface, hindering aquifer recharge and water infiltration (Cunha et al., 2008; Sampaio, 2008).

These characteristics require a detailed understanding of the spatio-temporal distribution of rainfall in the region in order to implement effective agricultural and livestock practices. The intermittency of rainfall and the limitations of the soils highlight the importance of management strategies that can adapt production to adverse climatic conditions, promoting the sustainability and resilience of economic activities in the Brazilian semi-arid region.

The delimitation criteria used to define which municipalities belong to the semi-arid region are based on climatic, socio-economic and environmental indicators. The analysis of the impacts of the new delimitation is indispensable for understanding how public policies and development programs will be affected. With this Resolution, space is opening up for discussions about the future of the region, considering the challenges and opportunities that arise with the new delimitation.

The climate in Ceará is characterized by a rainy season lasting three to five months, alternating with a dry period lasting up to nine months. During the rainy season, rainfall varies from 500 to 800 mm, which is essential for agriculture and water supply. During the dry season, high evapotranspiration rates and irregular rainfall are challenges faced throughout Ceará. Ceará has 95.11% of its municipalities belonging to the semi-arid region, thus having proportionally the largest number of municipalities compared to the other states.

The Brazilian semi-arid region is characterized by irregular rainfall, with scarce or absent rains in some years, both spatially and temporally. This phenomenon results in seasonal droughts, which are natural and recurrent in the history of the region, having been documented since the 17th century. Droughts directly affect farming activities, people's quality of life and the ecological and botanical characteristics of the area. The understanding of drought has evolved over the centuries, going through phases of denial, acceptance, “combat” and, finally, “coexistence”. Understanding drought from a historical perspective is crucial to assessing the influences of the technological and political approaches adopted to mitigate its effects (Mendes, 1986; Nunes, 2020).

Droughts can be classified into four main categories: meteorological, agricultural, hydrological and socioeconomic. Meteorological drought is defined by a lack of precipitation compared to normal, while agricultural drought is related to the availability of water in the soil for plants. Hydrological drought involves reduced water levels in reservoirs, affecting water supply and electricity generation. Socio-economic drought refers to the impacts of drought on human activities, resulting in shortages of goods and services such as energy and food. Understanding these categories allows for a better assessment and management of droughts, considering their multiple dimensions (Mishra; Singh, 2010; Fernandes et al., 2009).

The Brazilian Northeast, with 72.24% of its territory within the drought polygon, faces climatic challenges, such as long droughts and little rainfall. Despite this, local producers invest in techniques and technologies to make bovine milk production viable, which is essential for the regional economy. Definitions of the Semiarid vary, and are a source of confusion in parliamentary and governmental debates. According to Thornthwaite (1948), semi-arid regions have a ratio between precipitation and potential evapotranspiration of 0.20 to 0.50. Politically, the semi-arid region is defined by SUDENE's Deliberative Council based on criteria of aridity, precipitation and water deficit, making room for political criteria to prevail over technical ones (FAO, 2006; Lemos, 2020).

Milk production in the Brazilian semi-arid region faces numerous challenges due to the high temperatures, high humidity and intense exposure to the sun, which induce heat stress in cows and reduce their productivity. In addition, the milking environment influences milk quality, where inadequate facilities and sanitation difficulties increase the risk of contamination and negatively affect production. Physiological factors, such as genetics, stage of lactation, age, and nutrition, are also determinants of milk production. It is crucial to provide a suitable environment for the cows, taking into account climate, hygiene, food and available space (Baccari Jr., 2001; Bilby et al., 2009; Souza et al., 2004; Martello, 2006).

In the semi-arid region, the irregularity of rainfall and the caatinga vegetation are major obstacles. Low rainfall, high evaporation, and high temperatures affect animal productivity and reproduction, requiring supplementary feeding strategies such as forage palm, silage, and straw ammonization. Heat stress reduces feed intake, milk production and composition, reproductive efficiency and disease resistance. To minimize these effects, it is important to provide the animals with shade, fresh water and adequate ventilation. Climate instability, especially rainfall, has an impact on the availability and quality of pastures, increasing production costs and hindering the viability of enterprises, especially for small and medium-sized producers (Alves, 2008; Antonino et al., 2000).

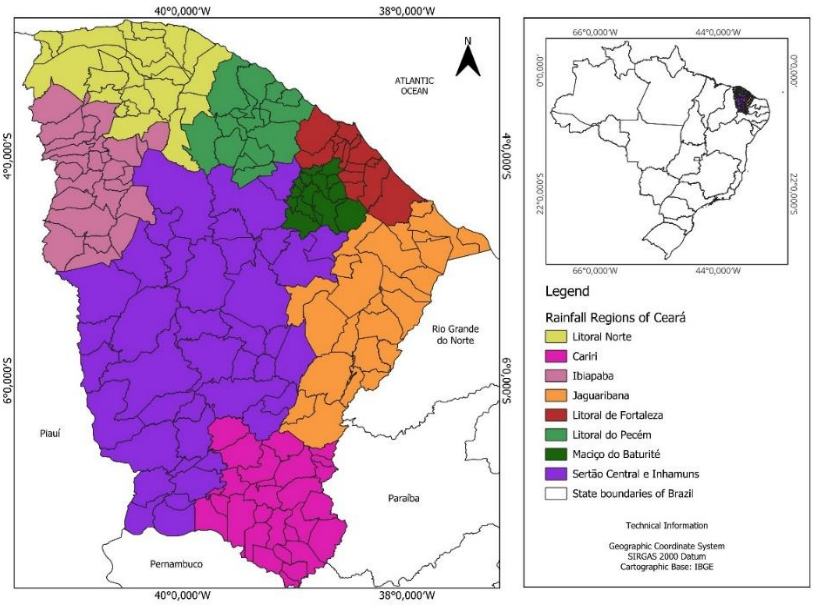
Producers in the northeastern semi-arid region are looking for nutritious food alternatives, such as forage palm, silage, sorghum, corn and cassava, which are adapted to local conditions. Leguminous forages such as Leucena and Gliricídia are also important, especially during periods of drought. These options help to overcome the challenges posed by adverse weather conditions, allowing milk production to be maintained in the region. The search for practices and technologies adapted to the specificities of the semi-arid region is fundamental to guaranteeing the sustainability and viability of dairy production, promoting regional economic development (Azevedo et al., 2008; Silva, 2009; Zoccal, 2008).

III. Material And Methods

Administratively, Ceará is divided into 184 municipalities. The regionalization adopted by the Secretariat of Planning and Management (SEPLAG) groups these municipalities into 14 Planning Regions: Cariri, Centro Sul, Grande Fortaleza, Litoral Leste, North coast, Litoral Oeste/Vale do Curu, Maciço de Baturité, Serra da Ibiapaba, Sertão Central, Sertão de Canindé, Sertão dos Crateús, Sertão dos Inhamuns, Sertão de Sobral and Vale do Jaguaribe. These regions are defined by geo-environmental, socio-economic and cultural characteristics and municipal flows. The state also has two Metropolitan Regions (Fortaleza and Cariri) and 18 administrative micro-regions (IPECE, 2021).

FUNCEME has divided Ceará into eight climatic regions to make it easier to understand its rainfall regime and which denote the characteristics defined below, with regard to milk production in 2022, according to IBGE. According to Figure 1:

Figure 1: Climate regions into which Ceará is divided by FUNCEME



Source - Based on data from FUNCEME (2020).

Sources of the data

This study uses rainfall and air temperature data made available by the National Oceanic and Atmospheric Agency (NOAA, 2020), covering the period from 1997 to 2020. It refers to information from the Sidra database and indicators provided by the Brazilian Institute of Geography and Statistics (IBGE) for the period 1997 to 2020, as found in the IBGE Statistical Yearbooks, and the Municipal Livestock Survey (PPM). Animal products, by type of product, also covering the period from 1997 to 2020. The observation units are all the municipalities in Ceará. All nominal values were corrected based on the year 2021. The Getúlio Vargas Foundation's IGP-DI was used for this purpose.

Variables used in the research

This research uses the following variables: Full Endogenous or Deterministic Endogenous (ENDO-DETR), which refers to herd size. It is assumed that the farmer decides the size of his dairy herd for each year. Endogenous non-deterministic or random (ENDO-ALEA): refers to the productivity of the herd. Although the farmer controls management and genetics, he has no influence over climatic variables such as rainfall and temperature. Exogenous with probabilistic forecasting capacity (EXOG-PREV): this is the case with the price of milk. The market sets the price, but the producer analyzes the prices of previous years to try to predict what might happen in the future. Totally unpredictable exogenous (EXOG-NPRV): these are variables such as rainfall and annual temperatures, which are beyond the producer's control and cannot be predicted accurately. In addition, there are constructed variables (CONS), which result from the combination of these variables, as summarized in Table 1.

Table no 1: Characteristics and definitions of the variables used in the research, associated with the i-th municipality and the t-th year, from 1997 to 2020.

Variables	Description
Y_{1it}	Number of lactating cows in the year
Y_{2it}	Productivity per cow (liter of milk/day)
Y_{3it}	Average annual rainfall (mm)
Y_{4it}	Annual average temperature (ºC)
Y_{5it}	Average annual price per liter of milk (R$2022/L)
Y_{6it}	Value of annual milk production (R$2022)
Y_{7it}	Quantity of milk produced in the year (L)

Source: Definition of the variables.

Analysis methods

The methodological procedures adopted to achieve each of the experiment's specific objectives are described below.

Methodology to achieve objective "a"

In order to achieve the results, set out in objective "a", the research aims to estimate the descriptive statistics associated with each of the variables studied: minimum values, maximum values, arithmetic mean, standard deviation and coefficient of variation. With this evidence, it will be possible to obtain a panoramic view of the behavior of the variables during the period under investigation, which extends from 1997 to 2020.

In addition to gauging the patterns of instability associated with the studied variables, the research uses the coefficient of variation (CV). The CV measures the percentage variation of the standard deviation in relation to the mean. The higher the CV, the more unstable the distribution of a variable's values around its mean. According to Gomes (1985), CVs are classified according to their amplitude.

By determining the CV of a data set, it is possible to compare it with the amplitude intervals shown in the table to classify the dispersion of the values. This classification provides valuable information on the homogeneity or heterogeneity of the indicators, helping in the analysis and interpretation of the results.

A CV of less than 10% indicates low dispersion: the values are concentrated close to the average, indicating a relatively homogeneous distribution. For a CV between 10% and 20%, there is moderate dispersion: the values are distributed around the average, but with greater amplitude compared to the "low" classification. When the CV is between 20% and 30%, there is high dispersion: the values express a large amplitude and are significantly different from the average, indicating a more heterogeneous distribution. Finally, a CV greater than 30% indicates extreme dispersion: the values are distributed in a very dispersed manner, with a great distance from the average, characterizing a highly heterogeneous distribution.

Methodology to achieve objective "b"

To achieve the second objective, two indices were created: the index of temporal instability in milk production in Ceará (INST) and the index of milk average production in Ceará (IMPR).

In order to estimate the INST, the research uses the synergy that exists between the coefficients of variation of the variables used in the research. In practice, the magnitude of the CV indicates how the values of a variable are distributed around its mean. The greater the dispersion, the higher the CV and the less the average will be able to gauge the accuracy of the distribution. The CV, therefore, measures the degrees of homogeneity/heterogeneity, or stability/instability of the distribution of the values of a variable around its mean (Lemos; Bezerra, 2019; Bezerra, 2022; Lessa, 2022)

The research estimates the CVs associated with the five (5) variables that define milk production in Ceará. As INST measures temporal instability, it will capture the behavior of the distributions of the values of the variables that define milk production in Ceará (production value, productivity and prices) around the respective averages in synergy with the climatic variables: CV of rainfall and temperatures. In order to capture the synergy between the CVs of the variables, the research used the method of factor analysis, with decomposition into principal components.

Similarly, the index of milk average production for Ceará (IMPR) was created. To estimate the IMPR, the average annual values of the variables that define milk production and the climate variables used in the research are calculated.

The IMPR is estimated through the synergy between the average annual values of the variables that define milk production and the climate variables. To capture this synergy, the research also uses the method of factor analysis, with decomposition into principal components.

Methodology to achieve objective "c"

For objective "c", as the procedures are the same for ranking the climate regions with both indices, we used the procedure for ranking by IMPR, which is shown in equation (8) below.

$IMPR_{ijt} = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \epsilon_{ijt}$ (8)

In this case, IMPR is the index estimated for region "k" in its municipality "i" 'and year' t " (t = 1997, 1998, ..., 2020), the variables Dk (k = 1, 2, ..., 7) are dummies (binary) that take on the following values:
D1 = 1 if the region is Cariri; or D1 = 0 in the other regions;
D2= 1 if the region is Ibiapaba; or D2 = 0 in the other regions;
D3 = 1 if the region is Jaguaribana; or D3 = 0 in the other regions;
D4= 1 if the region is the Fortaleza Coast; or D4 = 0 in the other regions;
D5 = 1 if the region is the North Coast; or D5 = 0 in the other regions;
D6 = 1 if the region is the Pecém Coast; or D6 = 0 in the other regions;
D7 = 1 = if the region is the Baturité Massif; or D7 = 0 in other regions.
When D1 = D2 = D3 = D4 = D5 = D6 = D7 = 0, the linear coefficient of equation (8) will be the average IMPR of the Sertão Central and Inhamuns regions.

If β_K (k = 1, 2,..,7) is statistically different from zero, it means that the average rainfall of the region is different. The random term ϵ_{ij}, by hypothesis, is white noise. According to Wooldridge (2011) and Gujarati and Porter (2011), if the hypotheses relating to the random terms are confirmed, the linear and angular coefficients of equation (8) can be estimated using the Ordinary Least Squares (OLS) method.

Based on the information provided, a hierarchy of Ceará's climatic regions is established in relation to the Index of Milk Production (IMPR). These hierarchies are organized in ascending or descending order, depending on the IMPR values for each region. If there are statistically significant differences in the indices between the regions, it is reasonable to assume that these differences influenced the behavior associated with milk production in Ceará during the period evaluated. The same procedure was carried out to assess whether the INST (Instability Index) is statistically different between the regions, as shown in the equation:

$INST_{ijt} = \beta_0 + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 + \beta_5 D_5 + \beta_6 D_6 + \beta_7 D_7 + \epsilon_{ijt}$ (9)

When D1 = D2 = D3 = D4 = D5 = D6 = D7 = 0, the linear coefficient of equation (8) will be the average INST of the Sertão Central and Inhamuns regions. If β_K (k = 1, 2,...,8) is statistically different from zero, it means that the average rainfall of the regions is different. The random term ϵij, by hypothesis, is white noise. According to Wooldridge (2011) and Gujarati and Porter (2011), if the hypotheses relating to the random terms are confirmed, the linear and angular coefficients of equation (8) can be estimated using the ordinary least squares (OLS) method.

In this case, INST is the index estimated for region "i" , municipality "j" and year "t" (t = 1997, 1998, ..., 2020), the variables D_k (k = 1, 2, ..., 7) are dummies (binary) variables that take on the following values:
D = 1 if the region is Cariri; or D_{cariri} = 0 in the other regions;
D1 = 1 if the region is Cariri; or D1 = 0 in the other regions;
D2= 1 if the region is Ibiapaba; or D2 = 0 in the other regions;
D3 = 1 if the region is Jaguaribana; or D3 = 0 in the other regions;
D4= 1 if the region is the Fortaleza Coast; or D4 = 0 in the other regions;
D5 = 1 if the region is the North Coast; or D5 = 0 in the other regions;
D6 = 1 if the region is the Pecém Coast; or D6 = 0 in the other regions;
D7 = 1 = if the region is the Baturité Massif; or D7 = 0 in other regions.
When D1 = D2 = D3 = D4 = D5 = D6 = D7 = 0, the linear coefficient of equation (9)

Methodology adopted to achieve objective "d"

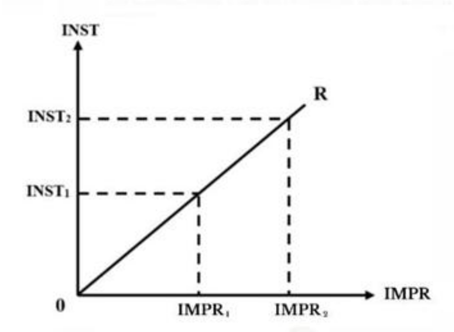
In the fourth objective, the research assessed the relationship between IMPR and INST in the state and regions. The IMPR, as shown in the methodology, integrates the average values of the variables that define milk production in Ceará from 1997 to 2020, in synergy with climate variables (average temperatures and average annual rainfall). Thus, this index aggregates the averages of the variables that define milk production, duly "contaminated" by rainfall and average annual temperatures. In turn, the instability index (INST) brings together the coefficients of variation associated with the variables that define milk production, together with the coefficients of variation associated with average annual temperatures and rainfall. Defined in this way, INST evaluates, in aggregate, the instabilities in milk production caused by the set of variables that influence it. INST is therefore interpreted as a gauge of the risks associated with average milk production in the period analyzed.

To make this connection, we refer to the work of Markowitz (1952), originally developed to determine the selection of portfolios in order to obtain an efficient combination of investments. According to this author, investors would look for combinations of investments that individually had expected values, but which indicated a joint variance, which would be the risk factor associated with the combinations. They would look for combinations with lower variances or lower risks. Applications with higher expected values would have higher variances and therefore higher risks. The goal would then be to find combinations that provide higher returns (higher expected values) with lower risks (lower absolute or relative variances).

In a paper written by Lemos (1995) adapted this Markowitz model for the combination of two types of agriculture in the state of Ceará: agriculture in which the cultivation of commodities grown by employers or commodities vis-à-vis agriculture grown by family units predominated.

In this research, only one productive activity is involved, which is milk production in Ceará, with its consequences for the climatic regions. The combination in this case is associated with climatic variables (temperature and rainfall) and the variables that define milk production. The hypothesis is that producers who combine the variables that lead to higher expected values, as measured by IMPR, will probably have higher relative variances (CV), which, in this research, are measured in aggregate by INST. Geometrically, the framework would be similar to the one illustrated in Figure 2.

Figure 2: Expected relationship between INST and IMPR, based on the application of the model proposed by Markowitz



Source: Adapted from Markowitz's model.

IV. Result And Discussion

Results found for the evaluation of Descriptive Statistics and Climate Instabilities in Milk Production in Ceará (1997-2020)

This subsection contains the results for the minimum (MN), maximum (MX), average values (AV), standard deviations (SD) and coefficients of variation (CV) associated with the variables studied in the research for Ceará from 1997 to 2020. Table 1 shows that rainfall showed medium instability (CV = 17.76%) on the scale proposed by Gomes (1985), while temperatures showed low instability, as expected, as measured by a CV of 2.47%.

The greatest instability was shown by the quantity of milk produced in the 184 municipalities, where the average was 2,489,635 liters and the CV was 129.51%. The instability estimated for the value of production, whose average annual value was R$5,516,626.00, was also very high, given the estimated CV of around 117.72%. With regard to lactating cows, whose annual average was 2927.82, the estimated CV of 106.11% was also classified as very high. The productivity of 0.62 liters per day had a CV equivalent to 26.81, representing high instability. Rainfall with a CV of 17.76% and prices with an average of R$2.45 had medium instability (Table 2)

Table no 2: Number of observations (N), minimum, maximum, average values, standard deviations and coefficients of variation of the variables studied from 1997 to 2020.

Variables	N	MN	MX	AV	SD	CV (%)
Temperature (ºC)	184	25.31	28.16	26.88	0.66	2.47
Rainfall (mm)	184	593.38	1215.88	866.84	153.95	17.76
Lactating cows (herds)	184	156.88	16837.29	2759.27	2927.82	106.11
Productivity (l/cows	184	1.41	4.61	2.30	0.62	26.81
Price (R$/l)	184	1.75	3.16	2.45	0.37	14.94
Milk (l)	184	136125	22400125	2489635	3224312	129.51
Production Value (R$)	184	405721.10	45655654.29	5516626.00	6494027	117.72

Sources: estimated values based on NOAA (2020) and IBGE (1997-2020) data.

The descriptive statistics estimated for the climatic regions of Ceará. Table 1 shows that the two largest average herds of lactating cows were in the Jaguaribana Region (4698 head) and the Central and Inhamuns Region (4578 herds). respectively. These two regions also showed the highest milk production averages in the period investigated. with 4.967.4 million and 4.026.7 million liters.

Temperatures expressed very low amplitudes. which are reflected in the low CVs estimated for all regions (2.47ºC). Therefore. the instabilities estimated in all of them are low. according to Gomes (1985). It can also be seen that, in general, rainfall indicated medium and low instabilities. with CVs ranging from 3.88% in the Cariri

Region to 13.52% in the Ibiapaba Region. The greatest instabilities measured by CV were observed in milk production and production values. all of which were very high.

Results found for the creation of the Indices of Temporal Instability (INST) and Milk Production (IMPR)

Based on the factor analysis applied to group the characteristics of the production variables with the climate variables. common or specific factors related to the level of production were identified. The estimates made by factor analysis. using the principal component decomposition technique to estimate IMPR and INST are shown in Table 3. From the evidence in this table, it can be seen that two orthogonal components were generated for both the IMPR and INST estimates. It can also be seen that the result of the Bartlet test. which assesses whether the correlation matrix is an identity. rejected the hypothesis that the correlations are null, at a level of at least 1% error. The KMO statistics were 0.609 and 0.626 respectively for the estimation of IMPR and INST. The total variance explained to estimate IMPR was 74.354%, while the total variance explained to generate INST was 63.45%. Therefore, these results provide an opportunity to develop both indices.

Table no 3: Results of factor analysis after orthogonal rotation to estimate INST.

Components for estimating IMPR			Components for estimating INST		
Variables	1	2	Variables	1	2
Temperature mean	-0.099	0.836	CV_temp	0.171	-0.539
Rainfall mean	-0.645	0.466	CV _rainfal	0.082	0.813
Cows mean	0.930	0.084	CV _cows	0.722	0.260
Productivity mean	0.307	0.773	CV _prod	0.623	-0.399
Price mean	-0.661	0.195	CV _price	0.154	0.746
Milk production mean	0.925	0.272	CV _production_milk	0.954	-0.007
Production value mean	0.901	0.286	CV_production value	0.910	-0.012
Kaiser-Meyer-Olkin (KMO) test		0.609	Kaiser-Meyer-Olkin (KMO) test		0.626
Bartlet Test (sig)		0.000	Bartlet Test (sig)		0.000
Total Explained Variance		74.354	Total Explained Variance		63.453

Sources: Estimated values based on data from IBGE (various years) and NOAA (2020).

Based on both tests, it was concluded that the sample used was adjusted to the factor analysis procedure. Therefore, the orthogonal transformation of the original factors was used. which denotes a solution in which each factor is more clearly related to certain variables. Orthogonal rotation was carried out using the Varimax method. which is widely used and produces simpler solutions. After orthogonal rotation. the component method analysis identified two characteristic roots with values greater than 1. Therefore, in order to interpret the results, it was decided to use two factors, taking into account the significant proportion of total variance captured by the original variables (Campos. 2016).

In IMPR, the first fator, i.e., the linear combination of the original variables that individually explains the largest portion of the variance, captured 49.86% of the total variance; the second fator, in order of contribution to the total variance, captured 24.49% of the total variance. In other words, the factors represent or capture a significant proportion of the variance information of the original variables.

In INST, the first factor captured 38.68%, while the second factor contributed to the total variance, capturing 24.77% of the 63.45% total variance in the data. Based on these results, it can be deduced that the factors represent or capture a significant proportion of the variance information of the original variables. The variances explained by each of the orthogonal componentes, which are used to estimate the weights for the IMPR and INST calculations, are shown in Table 4.

Table no 4: Estimates of the weights used to construct IMPR and INST.

Components	Generation of the weights to estimate the IMPR		Generation of the weights to estimate the INST	
	Explained variances		Components	
	Explained variances	Weights	Explained variances	Weights
Component 1	49.863	0.671	38.683	0.61
Component 2	24.492	0.329	24.769	0.39
Total	74.355	1.00	63.452	1.00

Sources: Estimated values based on data from IBGE (various years) and NOAA (2020).

Thus, the weights for estimating IMPR were 0.671 and 0.329, respectively, for orthogonal components 1 and 2. The weights for estimating INST were 0.610 and 0.390 for orthogonal components 1 and 2 respectively. Based on these weights, the IMPR and INST were estimated for each municipality in Ceará. The IMPR for the state averaged 0.310. The lowest estimated value for IMPR was 0.158 and occurred in the municipality of Pacujá, located in the Ibiapaba region. The highest IMPR was observed in the municipality of Morada Nova, situated in the Jaguaribana region, with a value of 0.959. In this region, therefore, milk production was the most successful in the period from 1997 to 2020, based on the synergy of the variables used in this investigation (Table no 4).

With regard to the estimated magnitude of INST, the lowest value of 0,097% was found in the municipality of Crateús, located in the Sertão Central and Inhamuns region. Therefore, this was the municipality with the lowest instability, based on the variables used in this study, among the 184 municipalities in Ceará studied in the research, from 1997 to 2020. On the other hand, the municipality of Palmácia, located in the Baturité massif region, had the greatest instability, with an INST = 0.912. The average INST was 0.334 (Table 4).

Table no 5 shows the results found for IMPR and INST in the 8 climatic regions of Ceará. It can be seen that the highest estimated average for IMPR occurred in the Jaguaribana Region (0.437), where the maximum value for IMPR was estimated for the Municipality of Morada Nova (0.959). The region with the second highest average value for the IMPR was the Fortaleza Coast (0,351), where the IMPR fluctuated between a minimum value of 0,252 in the municipality of Itaitinga and 0,590 in the municipality of Caucaia. On the other hand, the lowest estimated average value for the IMPR (0,221) was in the Ibiapaba Region, where the IMPR ranged from a minimum of 0.158 in Pacujá to a maximum of 0.316 in Forquilha.

Table no 5: Estimates of the minimum (MN). maximum (MX) and average (AV) values of the INST IMPR for the climate regions from 1997 to 2020.

Regions	IMPR by climate region			INST by climate region		
	Values			Values		
	MN	MX	AV	MN	MX	AV
Cariri	0.159	0.394	0.263	0.221	0.630	0.348
Ibiapaba	0.158	0.316	0.221	0.106	0.639	0.274
Jaguariban**a**	0.282	0.959	0.437	0.226	0.711	0.415
Fortaleza Coast	0.252	0.590	0.351	0.307	0.756	0.473
North Coast	0.191	0.393	0.271	0.140	0.472	0.279
Pecem Coast	0.224	0.481	0.331	0.153	0.581	0.265
Baturité Massif	0.203	0.279	0.246	0.155	0.912	0.391
S. Central and Inhamuns	0.173	0.895	0.348	0.100	0.640	0.304

Sources: Estimated values based on data from IBGE (various years) and NOAA (2020).

The two most unstable regions, as measured by INST, are the Fortaleza Coast (INST = 0.473) and Jaguaribana (INST = 0.415). These results confirm one of the hypotheses of this study, as these two regions had the highest production averages measured by IMPR (Table 5).

Results found for the ranking of Ceará's climatic regions, based on the INST and IMPR índices, respectively

In the third objective of this research, we tried to rank the climatic regions in two stages. In the first, we used the Index of Milk Production (IMPR); in the second, we used the Instability Temporal Index (INST). The results found at this stage of the research are shown in Table 6.

Table no 6: Regressions to define the differences in IMPR and INST estimated for the climatic regions of Ceará from 1997 to 2020.

Variables	Results found to estimate the IMPR			Results found to estimate theINST		
	Estimates	Student t	Sign.	Estimates	Student t	Sign.
(Constant: Dummy=0)	0.344	21.019	0.000	0.304	15.472	0.000
D1 = $Dummy_{Cariri}$	-0.082	-3.173	0.002	0.044	1.428	0.155
D2 = $Dummy_{Ibiapaba}$	-0.123	-4.686	0.000	-0.030	-0.941	0.348
D3 = $Dummy_{Jaguaruana}$	0.088	3.314	0.001	0.108	3.401	0.001
D4 = $Dummy_{Fortaleza}$	0.005	0.169	0.866	0.165	4.232	0.000
D5 = $Dummy_{North}$	-0.075	-2.665	0.008	-0.024	-0.726	0.469
D6 = $Dummy_{Pecem}$	-0.013	-0.432	**0.666**	-0.039	-1.054	0.293
D7 = $Dummy_{Baturité}$	-0.095	-2.844	0.005	0.094	2.349	0.020
Adjusted R^2	0.265			0.178		

Sources: Estimated values based on data from IBGE (various years) and NOAA (2020).

From the results expressed in Table 5, it can be seen that the climatic regions assume the following hierarchy, according to IMPR:
Jaguaribana > Fortaleza Coast = Sertão Central and Inhamuns = Pecém Coast > Norte Coast > Cariri > Baturité Massif > Ibiapaba.

Thus. according to the IMPR. the original eight climatic regions are reduced to six regions, given that the Fortaleza Coast, Sertão Central and Inhamuns, and Pecém Coast regions have statistically equal IMPR's and thus constitute a single region, according to this indicator.

The Jaguaribana Region leads in milk production, standing out as the main producer among the regions. The introduction of dairy cattle breeds with higher productivity and the practice of genetic crossbreeding have improved the quality of the herd, positively influencing productivity. Another important factor has been the implementation of advanced pasture management techniques and food supplementation, which has improved cattle nutrition. resulting in higher milk production.

The Fortaleza Coast, Sertão Central and Inhamuns as well Pecém coast regions have similar milk production, justifying their merger into a single region for the purposes of production analysis. This grouping indicates that, despite the different geographical and climatic characteristics, milk production is balanced between these areas. In the North Coast region, milk production is lower, compared to the regions already mentioned, placing it in the middle of the hierarchy. The Cariri region has lower milk production than the North Coast, but it is still significant compared to the regions with lower production. Ibiapaba has the lowest milk production among the regions analyzed, coming last in the hierarchy.

The simplification of the eight climatic regions into six, based on IMPR, makes it easier to analyze and compare milk production. This hierarchy gives the opportunity to clearly identify the areas with the highest and lowest production, helping to make strategic decisions to improve milk production in the less productive regions and boost those that already have high production. As for the evidence expressed in Table 6 in relation to the Instability Indexes (INST), is constructed the following hierarchy:

Fortaleza Coast > Jaguaribana > Baturité Massif > Cariri = Sertão Central and Inhamus = North Coast= Ibiapaba = Pecém Coast.

According to INST, the eight climatic regions of Ceará are reduced to 4 regions, given that the INST's estimated for the Cariri, Sertão Central and Inhamuns, North Coast, Ibiapaba and Pecém Coast regions are not statistically different and, in this way, they become one of the four regions in which this indicator maps the regions of Ceará.

Raising dairy cattle involves a series of risks capable of impacting both productivity and the profitability of producers. The Fortaleza Coast Region is the one with the highest milk production risk, this is due to a variety of factors: climate vulnerabilities, impact on fodder production, fluctuations in input prices, fluctuations in milk prices and logistical challenges. This result confirms Markowitz's proposition that greater economic results are associated with greater risks, especially when applied to agricultural activities

The Jaguaribana Region, although it has high milk production, also denotes significant risk, which is likely to be related to the large investment in dairy farming. The greater the investment. the greater the risk of financial return from the activity. The Baturité Massif expresses intermediate risk. This may be due to specific factors, such as the mountainous terrain, which certainly makes logistics more difficult and increases production costs, as well as local climatic variability.

Cariri, Sertão Central and Inhamuns, North Coast, Ibiapaba, Pecém Coast express the lowest risk of milk production, according to INST. The statistical similarity between the indices of these regions suggests that they share relatively favorable conditions or common challenges that balance each other out, making milk production less risky compared to the other regions studied, the regions of Cariri, Sertão Central and Inhamuns, North Coast, Ibiapaba and Pecém Coast have statistically equal INST indices. Therefore, these five regions will be grouped into a single region for risk analysis purposes.

Results found for analyzing the relationship between the IMPR and INST indices in the state of Ceará and the climate regions

In objective “d”, the research sought to assess the relationship between IMPR and INST. To carry out this stage of the research. Pearson's linear correlation coefficients were estimated between the two indices created in the research for the state as a whole and for the regions into which the state was organized, after the two indices had been ranked. As INST is more limiting, because it reduces the original 8 regions to 4, it was decided to estimate the correlation coefficients based on these 4 regions. These results are shown in Table no 7.

As shown in the results for objective “c”, the Cariri, Sertão Central and Inhamuns, North Coast, Ibiapaba and Pecém regions were grouped into just one. Their data was therefore aggregated to estimate the Pearson correlation coefficients shown in Table no 7.

The evidence presented in Table no 7 shows that the hypothesis of a positive correlation between IMPR and INST is supported. For instance, for Ceará State, the estimated value was 0.223. This result indicates that in the municipalities with the highest IMPR - in other words, with the highest averages of the variables studied in the research - farmers had greater instability in the synergy between these variables. It is worth noting that, from this perspective, they took greater risks, according to Markowitz.

The results also show that in the Jaguaribana ($IMPR_{mean}$ = 0.432) and Fortaleza Coast ($IMPR_{mean}$ = 0.349) regions, which had the highest IMPR, they also had the highest INST mean of 0.412 and 0.469 respectively. The Pearson correlation coefficients estimated for these two regions were the highest at 0.325 and 0.221 respectively. Therefore, farmers in these two regions managed to achieve better results in milk production, but also incurred greater instabilities or risks.

Table no 7: Pearson's linear correlation (R) estimated between the two indices for the climate regions redefined by INST and for the state of Ceará between 1997 and 2020.

	Results for IMPR			Results for INST			
Region	MN	MX	Mean	MN	MX	Mean	R_{IMPR_INST}
Cariri	0.159	0.394	0.262^{D}	0.221	0.630	0.348^{D}	0.096
Ibiapaba	0.158	0.316	0.221^{F}	0.106	0.639	0.274^{D}	0.096
Jaguaribana	0.282	0.959	0.432^{A}	0.226	0.711	0.412^{B}	0.325
Fortaleza Coast	0.252	0.590	0.349^{B}	0.307	0.756	0.469^{A}	0.221
North Coast	0.191	0.393	0.269^{C}	0.140	0.472	0.280^{D}	0.096
Pecém Coast	0.224	0.481	0.331^{B}	0.153	0.581	0.265^{D}	0.096
Baturité Massif	0.203	0.279	0.249^{E}	0.155	0.912	0.398^{C}	0.069
Sertão Central and Inhamuns	0.173	0.895	0.344^{B}	0.097	0.636	0.304^{D}	0.096
Ceará	0.159	0.959	0.310	0.097	0.913	0.334	0.223

Sources: Estimated values based on data from IBGE (various years) and NOAA (2020). Note: The super-indices associated with the averages should be understood in the following hierarchy: A > B > C > D > at least at the 5% error level.

V. Conclusion

The research revealed that, despite low rainfall, semi-arid regions can achieve high dairy productivity when significant investments are made in genetic improvement, feeding and management. These areas of high productivity, however, also presented greater risks according to the instability index confirming the Markowitz proposal tested in this search. The Jaguaribana region, specifically in the municipality of Morada Nova, stood out with high productivity, even with na anual average rainfall of 751 mm. In contrast, the Ibiapaba region, despite having a higher average rainfall (1086 mm/ year), recorded lower yields. This shows that factors such as genetics, stored forage and management have a greater impact on milk production than the amount of rainfall.

The research confirmed Markowitz's theory, which suggests that higher levels of production are associated with greater instability and risk. Regions such as Jaguaribana and Fortaleza. which showed high production rates, also showed the highest instability rates. This correlation suggests that producers need to be bold, investing more in the quality and management of their herds in order to achieve better results. Dairy production, particularly in the semi-arid region, is subject to climatic variations that directly affect productivity and pasture availability, increasing production costs and requiring strategies such as the use of supplementary fodder.

The research also showed that the search for higher expected production values is associated with greater risks, a common reality in agricultural activities. Family farmers often diversify their production to minimize these risks, but milk production. as a single activity, forces them to take on more risk. In the Brazilian semi-arid region, this need for innovation and daring is even more crucial due to climate instability. The results confirmed that monolithic agricultural activities, without diversification, are subject to many risks. Therefore, dairy farmers in the Brazilian semi-arid region need to adopt innovative and efficient practices to deal with these challenges.

Among the innovations suggested to improve milk production are mechanical milking, tracking and identification technologies, remote monitoring with drones, and intelligent feeding systems. In addition, technical assistance, access to credit, and support policies, such as Agro-Nordeste Digital, are essential to improve the conditions of producers. This program aims to foster technological entrepreneurship and strengthen agricultural innovation ecosystems in the region, promoting rural connectivity and learning networks.

Future work exploring the risks associated with milk production in the municipalities of the Northeast located in the semi-arid region is pertinent. Due to its monolithic nature, dairy farming poses significant challenges for farmers, who need to master several variables in order to achieve success. The research concludes that farmers in the semi-arid region must be innovative and daring in order to deal with the risks inherent in dairy farming in this region.

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