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Comparison of k-means clustering with hierarchical agglomerative clustering for the analysis of food security of rice sector in Indonesia

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ABSTRACT

Indonesia's food security depends on the availability and distribution of rice as a staple food. To support data-driven policies, this study applies K-Means Clustering and Hierarchical Agglomerative Clustering (HAC) to cluster 38 provinces based on rice consumption and production patterns. Data is sourced from BPS with attributes: rice consumption per capita, rice production, rice price per kg, and population. These variables were chosen because they reflect the balance of demand, supply, affordability, and food needs. The optimal number of clusters was determined as three, based on Elbow Method and Silhouette Score for K-Means, and Dendrogram and Cophenetic Correlation Coefficient (CCC) for HAC. The clustering results identify regional characteristics related to food security and support the formulation of more targeted rice distribution policies. This study also compares the effectiveness of both methods in supporting equitable and sustainable food distribution strategies.

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Introduction

Indonesia is an agricultural country where agricultural activities are very important for food security (Rozaki, 2021; Sintiya, 2023). One of the food crops that has an important role in supporting food security is the rice commodity (Marzani & Juliannisa, 2024). One of the staple foods, rice, is often consumed and supports two-thirds of the world's population (Kasote et al., 2022; Mohidem et al., 2022). Therefore, the sustainability of rice production and distribution is an important factor in maintaining the stability of food security in Indonesia. In Indonesia, food availability is synonymous with rice availability (Rusadi Akhmad, 2023). The balance between rice production and consumption is something that needs to be considered because there are differences in the fulfillment of consumption in each region. In maintaining this balance, the most influential factor is the population (Marzani & Juliannisa, 2024).

The imbalance in rice production and consumption may raise concerns about a potential food crisis in the future (Mavroeidis et al., 2022). If the population continues to increase while the availability of rice is insufficient, the short-term solution is imports. However, dependence on imports is not an ideal solution in the long run (Setiani et al., 2021). Therefore, the government is expected to formulate an effective strategy to increase rice production while ensuring its equitable distribution throughout the region. According to Saefudin from the Planning Bureau of the Secretariat General of the Ministry of Agriculture (2023), the government seeks to increase the area of cultivated land to boost rice production, with the target of reducing imports by 2024 and achieving rice self-sufficiency by 2025. In addition, there is a grand vision to make Indonesia the world's food barn in the next ten years.

Indonesia is predicted to continue to experience a demographic bonus in the next few years (Adriani & Yustini, 2021; Dwi Ariyanti et al., 2024). Based on data from the BPS (2024) Indonesia's population will be 281.6 million in 2024. This number increased by 1.04% compared to last year. According to BPS (2025), rice production in 2024 for food consumption by the population is estimated at 30.62 million tons, 480.04 thousand tons or 1.54 percent less than rice production in 2023 which amounted to 31.10 million tons. In addition, a report from United States Department of Agriculture (2024) that the total rice consumption of the Indonesian population in 2024 will be 36.5 million tons. If the trend of population growth and rice consumption continues to increase while rice production continues to decline, then national food security is threatened because the increase in population and demand is not matched by adequate availability. This condition highlights the urgent need for a region-based food security analysis that identifies disparities in rice availability and consumption across provinces. Such analysis will assist policymakers in formulating equitable and targeted distribution policies based on objective data segmentation. However, existing studies tend to focus on general national food security indicators without leveraging data clustering techniques to reveal patterns of surplus and deficit areas. This creates a clear research gap, where data-driven cluster analysis can provide strategic insights into the distribution of rice commodities at a regional level.

In this context, the government needs to formulate appropriate food security policies to maintain a balance between rice availability and consumption across regions. This research implements K-Means Clustering and Hierarchical Agglomerative Clustering (HAC) methods to cluster regions based on rice availability and consumption patterns. K-Means works by grouping data into k clusters based on the distance to the nearest centroid, then updating the centroid until it converges or reaches the maximum iteration (Ay et al., 2023; Oti et al., 2021). Meanwhile, HAC works with a bottom-up approach, meaning that each piece of data is considered a separate cluster and gradually combined based on similarities to form the final cluster (Chhabra & Mohapatra, 2022; Yu & Hou, 2022). These two clustering techniques are suitable because they are capable of handling multivariable data and identifying hidden patterns in food production and consumption. K-Means provides efficient partitioning, while HAC offers a hierarchical view of similarity between regions. Applying both methods provides a comprehensive analysis for determining potential surplus and deficit zones. Although clustering is not a decision-making tool per se, it serves as an analytical foundation to support regional food policy formulation in a more targeted and evidence-based manner.

One of the previous studies that became a reference was research conducted by Tuslaela et al (2024) that discusses the application of the K-Means Clustering method to cluster 29 districts in East Java based on land area and rice production in 2022. The results produce two clusters, namely high production (4 districts) and low production (25 districts), which can be used to support food security policies. Validation using the Davies-Bouldin Index shows good clustering results and is relevant for agricultural aid distribution planning. One of the studies conducted using HAC is the research Ratnasari & Dani (2023). This study aims to map the food security conditions of 34 provinces in Indonesia using the CEBMDC-ROCK method, which is a combination of Agglomerative Hierarchical Clustering (for numerical data) and Robust Clustering Using Links (ROCK) (for categorical data), in order to optimally cluster regions based on mixed data. The variables used include numerical indicators such as poverty percentage, access to clean water and electricity, and categorical indicators such as human development index (HDI) and stunting prevalence, which are then clustered to get a picture of the quality of food security in each province. The analysis results in five clusters that show variations in the quality of food security from very high to very low, which can be the basis for formulating strategies and policies for central and local governments so that the distribution of food security in Indonesia becomes more equitable and targeted. Based on references from previous studies, this research contributes by implementing the K-Means and HAC methods specifically in food security analysis, to cluster regions based on rice consumption, production, rice price, and population, so as to identify regions that experience surpluses and deficits as a basis for formulating more equitable and data-based rice distribution policies.

Method

K-Means Clustering Algorithm

The K-Means algorithm is an iterative clustering algorithm that partitions a dataset into k predefined clusters. The K-Mean Clustering algorithm is presented below (Ahmad & Khan, 2021; Zubair et al., 2024):

1) Determine the desired number of clusters (k) in the dataset.
2) Determine the initial cluster center (centroid) by taking the smallest, average and largest values.
3) Calculating the closest distance between each data and the Centroid. Calculating the closest distance to the Centroid uses the Euclidean distance formula. The formula can be seen below:

$$\boldsymbol{d(xi, \mu j) = \sqrt{(xi - \mu j)^2}} \quad (1)$$

Description:
$\boldsymbol{xi}$: Criteria data
$\boldsymbol{\mu j}$: Centroid of the jth cluster

4) Recalculate the Cluster center with the current Cluster members. The formula can be seen below:

$$\boldsymbol{\mu j(t+1) = \frac{1}{Nsj} \sum j \in Sj\ xj} \quad (2)$$

Description:
$\boldsymbol{\mu j(t+1)}$: New centroid at the 1st iteration
$\boldsymbol{Nsj}$: Number of data in cluster sj;

Hierarchical Agglomerative Clustering (HAC) Algorithm

Hierarchical Agglomerative Clustering is a clustering method that builds a hierarchy of data with a bottom-up approach, namely by combining data points one by one until they form one large cluster. The HAC algorithm is presented as follows (Chhabra & Mohapatra, 2022; Monath et al., 2021):

1) Calculating the Euclidean distance matrix (as in Formula 1).
2) Merge the two closest clusters. If the distance between objects a and b has the smallest distance value compared to the distance between other objects in the Euclidean distance matrix, the combined two clusters in the first stage is d_ab.
3) Update the distance matrix according to the Agglomerative method clustering technique If d_ab is the closest distance from the Euclidean distance matrix, then the formula for the agglomerative method is:

   a. Single linkage formula

$$\boldsymbol{d_{(ab)c} = min\{d_{a,c}; d_{b,c}\}} \quad (3)$$

   b. Average linkage formula

$$\boldsymbol{d_{(ab)c} = average\{d_{a,c}; d_{b,c}\}} \quad (4)$$

   c. Complete linkage formula

$$\boldsymbol{d_{(ab)c} = max\{d_{a,c}; d_{b,c}\}} \quad (5)$$

4) Repeating steps 2 and 3 until only one cluster remains
5) Drawing up the Dendrogram

Tools and Libraries

This research utilizes the Python programming language to implement the K-Means and Hierarchical Agglomerative Clustering (HAC) algorithms. Several essential libraries must be installed beforehand to ensure proper execution in the Kaggle Notebook environment. The pandas library is employed for data manipulation and analysis in tabular form, while numpy facilitates numerical computations and operations on multidimensional arrays. For data visualization, matplotlib.pyplot is used to generate various graphical representations, and seaborn enhances statistical data visualization with a more aesthetically appealing design. To ensure uniform scaling of the dataset, StandardScaler from the sklearn.preprocessing module is applied for data normalization. The effectiveness of clustering is assessed using the silhouette_score function from sklearn.metrics. The KMeans module from sklearn.cluster is implemented to perform K-Means clustering, while hierarchical clustering is carried out using linkage and dendrogram from scipy.cluster.hierarchy to construct dendrograms and compute linkage matrices. Additionally, AgglomerativeClustering from sklearn.cluster is utilized to implement the HAC algorithm, allowing the formation of hierarchical clusters based on data similarity. These libraries collectively support the clustering process, ensuring accurate analysis and meaningful interpretations of the results.

Research Stages

The research subjects in this study are provinces in Indonesia that are analyzed based on rice consumption and production data. The object of the study includes rice consumption and production patterns in each province, which are clustered using the K-Means Clustering and Hierarchical Agglomerative Clustering methods. The data used is obtained from the BPS and includes indicators such as rice consumption per capita per year, rice production, rice price per kilogram, and population in each province. The clustering results aim to identify regions with similar characteristics to support the formulation of national food security policies in a more targeted manner.

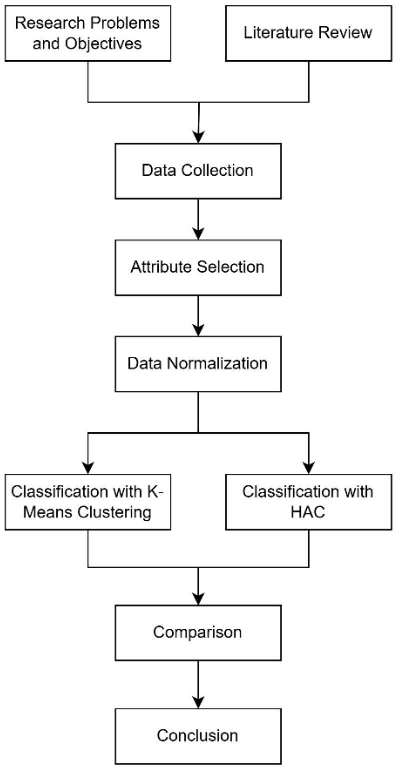

Figure 1 Flowchart of Research Phase

Problem and Research Objectives

This study begins with the identification of the problem and research objectives, which are to analyze food security based on rice consumption and production patterns in various provinces in Indonesia. The main focus of the research is to find rice distribution patterns to support more appropriate policy making.

Literature Review

Next, a literature review was conducted to examine previous research relevant to data classification in the context of food security. The methods used in this research, namely K-Means Clustering and Hierarchical Agglomerative Clustering, were chosen based on their effectiveness in grouping data based on certain patterns.

Data Collection

This stage involves collecting data from official sources, namely the Central Bureau of Statistics (BPS). The data collected included provincial variables, annual per capita rice consumption, rice production, rice price per kilogram, and population in each province.

Table 1 Research Dataset

Province	Annual Rice Consumption per capita (Kg)	Price of Rice per Kg (Rp)	Production (Kg)	Total Population
Aceh	86,164	15670	947840746	5554800
Sumatera Utara	94,692	15230	1258983916	15588500
Sumatera Barat	78,572	17420	774543188	5836200
Riau	75,244	16220	126793810	6728100
Jambi	75,244	15830	160463591	2183300
Sumatera Selatan	84,188	15440	1661274064	3724300
Bengkulu	89,596	15070	155796522	8837300
Lampung	81,952	15990	1593859440	1531500
Kepulauan Riau	72,696	15890	44246670	2112200
Kepulauan Bangka Belitung	64,428	17310	174206	9419600
DKI Jakarta	68,588	16310	1317034	10684900
Jawa Barat	80,132	16650	4925948429	50345200
Jawa Tengah	68,796	16360	5076930616	12431400
DI Yogyakarta	62,66	16330	258566941	37892300
Jawa Timur	74,828	15760	5293418551	3759500
Banten	83,2	16570	885405996	41814500
Bali	96,148	16860	362855283	5695500
Nusa Tenggara Barat	99,112	16580	829896179	2809700
Nusa Tenggara Timur	107,432	16440	404149540	4273400
Kalimantan Barat	84,188	17140	436691750	4045900
Kalimantan Tengah	79,092	17250	209069834	739800
Kalimantan Selatan	76,232	16600	587883288	2701800
Kalimantan Timur	71,812	17520	142546096	1227800
Kalimantan Utara	75,4	17190	17175549	3121800
Sulawesi Utara	91,52	15370	155960051	9463400
Sulawesi Tengah	94,068	16100	435065679	1503200
Sulawesi Selatan	90,948	15720	2751323182	2793100
Sulawesi Tenggara	92,404	15890	317382402	4433300
Gorontalo	91,104	17000	134106705	5646000
Sulawesi Barat	100,412	14660	182078533	5656000
Maluku	81,848	17430	52032575	1945600
Maluku Utara	78,728	17860	17834014	1355600
Papua	68,12	15840	11836345	1090000
Papua Barat	66,04	16980	564513	569900
Papua Selatan	66,872	16000	2632281	545900
Papua Tengah	52,104	27810	124357873	1360000
Papua Pegunungan	60,268	25340	3467329	1466700
Papua Barat Daya	46,28	18440	24199	616100

Attribute Selection

After the data was collected, the most relevant attributes for the classification analysis were selected. The selected attributes include annual per capita rice consumption, rice production, rice price per kilogram, and population in each province as shown in Table 2.

Table 2 Selected Attributes

No	Selected Attributes
1	Annual Rice Consumption per capita (Kg)
2	Rice Price per Kg (Rp)
3	Production (Kg)
4	Total Population

Data Normalization

The data obtained has a different scale, so it is necessary to normalize it to ensure that there are no variables that dominate in the clustering process. Normalization is done so that the K-Means and GMM methods can provide optimal results. Examples of the top 5 (five) data from the research dataset are listed in Table 3.

Table 3 Pieces of Data Normalization Results

Annual Rice Consumption per capita (Kg)	Price of Rice per Kg (Rp)	Production (Kg)	Total Population
0.519782	-0.527737	0.107964	-0.165741
1.159956	-0.709259	0.332960	0.731621
-0.050129	0.194224	-0.017352	-0.140574
-0.299953	-0.300835	-0.485757	-0.060807
-0.299953	-0.461729	-0.461410	-0.467270

Clustering Using K-Means Clustering and Hierarchical Agglomerative Clustering

In this stage, the data is clustered using the K-Means Clustering method based on the similarity of rice consumption and production patterns in each province. This method works by grouping data into a number of clusters based on the distance to the nearest centroid, then updating the centroid position until the clustering result is stable. In addition to K-Means, classification was also performed using Hierarchical Agglomerative Clustering (HAC), which groups data hierarchically based on similarities between provinces. This method works by gradually combining provinces that have the most similar characteristics until the final cluster is formed. HAC uses a distance and linkage-based approach to determine the relationship between data, resulting in a clearer and more interpretative cluster structure than K-Means.

Comparison of Results

After the clustering process is complete, the results of the two methods are compared by looking at the comparison graph of the clustering results as well as the interpretation obtained from the data visualization. From the resulting graphs, we can analyze the distribution of clusters formed, the distribution pattern of provinces within each cluster, and how the two methods group provinces based on rice consumption patterns, rice prices, rice production, and population. The conclusions from this comparison help determine which method is more suitable in describing food security patterns in each province.

Conclusion

The final stage is to conclude the research results. The conclusion includes an interpretation of the clustering patterns formed, as well as recommendations for food security policies based on areas with similar characteristics. The results of this study are expected to serve as a reference in determining a more effective rice distribution strategy.

Results and Discussions

Clustering Using K-Means Clustering

The stage starts from determining the number of clusters for the K-Means Clustering method using the Elbow Method whose results are as shown in Figure 2, and using Silhouette Score to assess the optimal cluster score based on the Elbow Method as shown in Figure 3. The results of the two graphs presented show that the optimal cluster used is as many as 3 clusters for further use in the K-Means Clustering method.

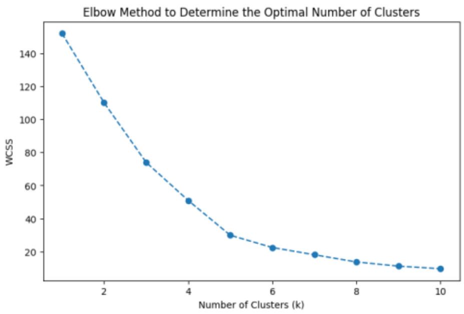

Figure 2 Elbow Method Results

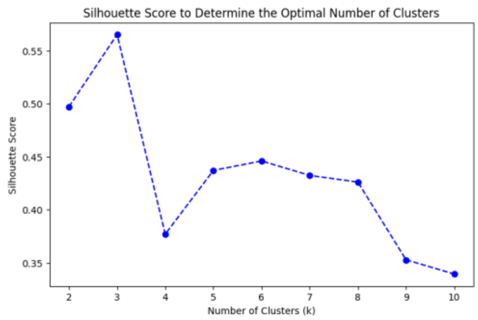

Figure 3 Silhouette Score Results

Clustering is done with the K-Means method, the results of which are as shown in table 4.

Table 4. Clustering Results with K-Means Clustering

Province	Annual Rice Consumption per capita (Kg)	Price of Rice per Kg (Rp)	Production (Kg)	Total Population	KMeans Cluster
Aceh	86.164	15670	947840746	5554800	1
Sumatera Utara	94.692	15230	1258983916	15588500	1
Sumatera Barat	78.572	17420	774543188	5836200	1
Riau	75.244	16220	126793810	6728100	1
Jambi	75.244	15830	160463591	2183300	1
Sumatera Selatan	84.188	15440	1661274064	3724300	1
Bengkulu	89.596	15070	155796522	8837300	1
Lampung	81.952	15990	1593859440	1531500	1
Kepulauan Riau	72.696	15890	44246670	2112200	1
Kepulauan Bangka Belitung	64.428	17310	174206	9419600	1
DKI Jakarta	68.588	16310	1317034	10684900	1
Jawa Barat	80.132	16650	4925948429	50345200	3
Jawa Tengah	68.796	16360	5076930616	12431400	3
DI Yogyakarta	62.66	16330	258566941	37892300	1
Jawa Timur	74.828	15760	5293418551	3759500	3
Banten	83.2	16570	885405996	41814500	1
Bali	96.148	16860	362855283	5695500	1
Nusa Tenggara Barat	99.112	16580	829896179	2809700	1
Nusa Tenggara Timur	107.432	16440	404149540	4273400	1
Kalimantan Barat	84.188	17140	436691750	4045900	1
Kalimantan Tengah	79.092	17250	209069834	739800	1
Kalimantan Selatan	76.232	16600	587883288	2701800	1
Kalimantan Timur	71.812	17520	142546096	1227800	1
Kalimantan Utara	75.4	17190	17175549	3121800	1
Sulawesi Utara	91.52	15370	155960051	9463400	1
Sulawesi Tengah	94.068	16100	435065679	1503200	1
Sulawesi Selatan	90.948	15720	2751323182	2793100	1
Sulawesi Tenggara	92.404	15890	317382402	4433300	1
Gorontalo	91.104	17000	134106705	5646000	1
Sulawesi Barat	100.412	14660	182078533	5656000	1
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Maluku Utara	78.728	17860	17834014	1355600	1
Papua	68.12	15840	11836345	1090000	1
Papua Barat	66.04	16980	564513	569900	1
Papua Selatan	66.872	16000	2632281	545900	1
Papua Tengah	52.104	27810	124357873	1360000	2
Papua Pegunungan	60.268	25340	3467329	1466700	2
Papua Barat Daya	46.28	18440	24199	616100	1

The visualization of the relationship between attributes can be seen in Figure 4.

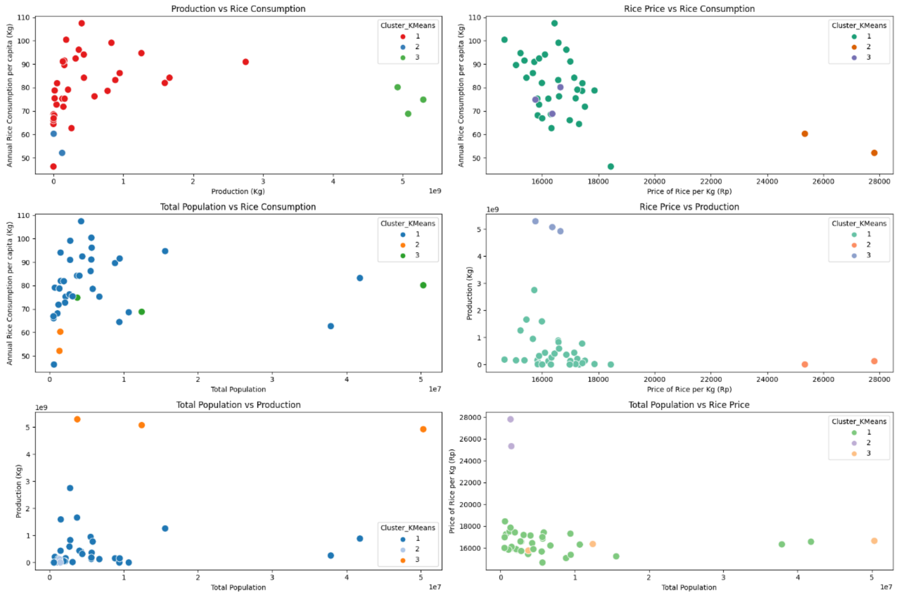

Figure 4 Visualization of Relationship Between Attributes with K-Means Clustering

Clustering Using Hierarchical Agglomerative Clustering

The stage starts from determining the number of clusters for the HAC method by using the linkage = single method which results in a dendrogram as shown in Figure 6. The dendrogram was evaluated with the Cophenetic Correlation Coefficient (CCC) to assess the optimal cluster score. The results of the dendrogram presented show that the optimal cluster used is 3 clusters and the CCC score obtained is 0.9167 which indicates that by using 3 clusters based on the dendrogram, HAC is very good and can be used to determine the optimal cluster with high confidence.

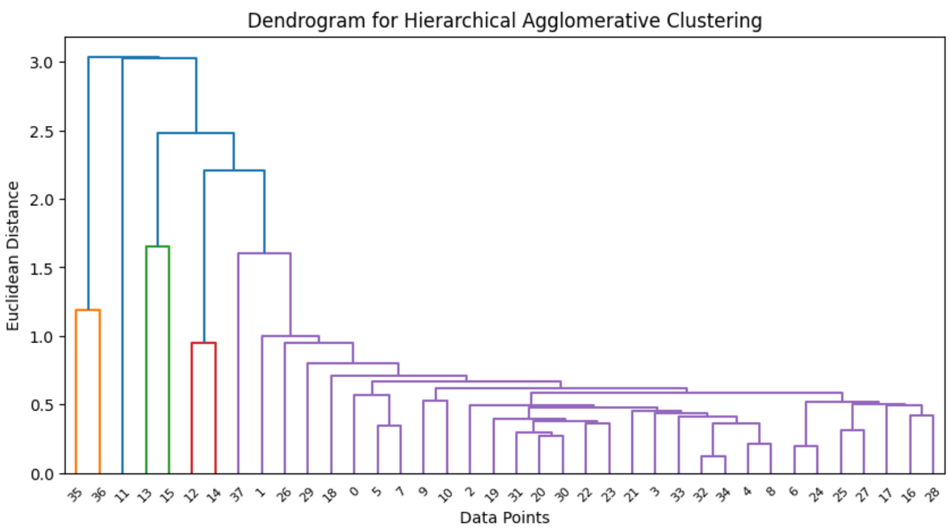

Figure 5 Dendrogram for Hierarchical Agglomerative Clustering

Furthermore, clustering is carried out with the HAC method, the results of which are as shown in table 5.

Table 5. Clustering Results with Hierarchical Agglomerative Clustering

Province	Annual Rice Consumption per capita (Kg)	Price of Rice per Kg (Rp)	Production (Kg)	Total Population	KMeans Cluster
Aceh	86.164	15670	947840746	5554800	1
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The visualization of the relationship between attributes can be seen in Figure 6.

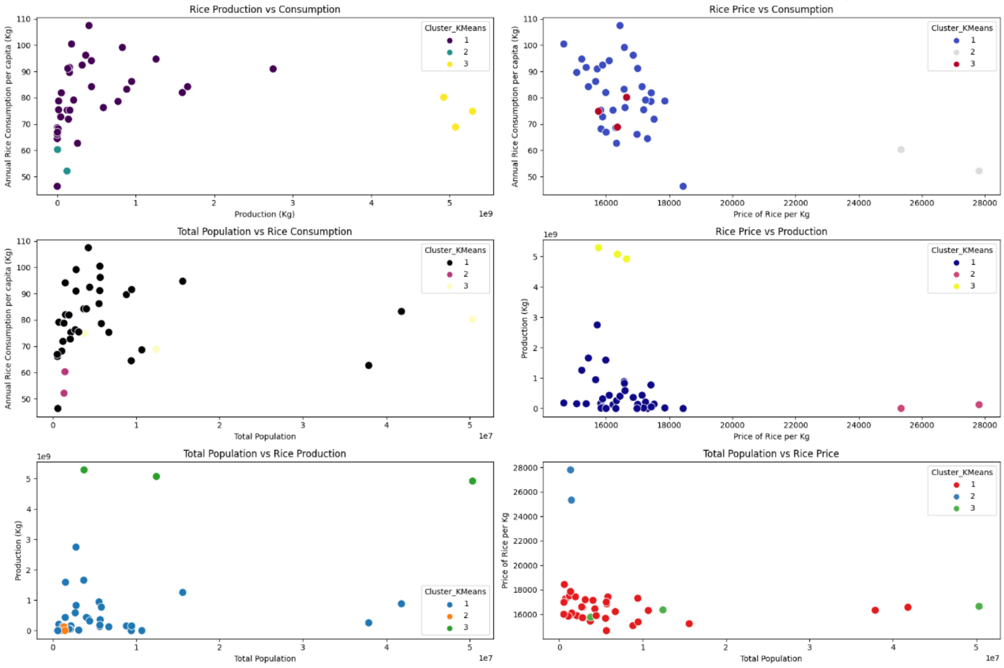

Figure 6. Visualization of Relationships Between Attributes with Hierarchical Agglomerative Clustering

Comparison of Results

Based on the clustering results using 2 (two) different methods, K-Means Clustering and Hierarchical Agglomerative Clustering recommend the same number of clusters, namely 3 (three) clusters. is Province data by cluster listed in Table 4 and analysis of each cluster are listed in Table 6.

Table 6 Province Data by Cluster

	K-Means	HAC
Number of Clusters	3	3
Cluster 1	Other than Clusters 2 and 3	Other than Clusters 2 and 3
Cluster 2	• Papua Tengah • Papua Pegunungan	• Papua Tengah • Papua Pegunungan
Cluster 3	• Jawa Barat • Jawa Tengah • Jawa Timur	• Jawa Barat

Table 7 Analysis of Attributes in Each Cluster

Mean of	Cluster	K-Means	HAC	Analysis
Rice Consumption (Kg per capita per year)	Cluster 1	81.06	80.53	Moderate consumption, most provinces
	Cluster 2	56.19	56.19	Lowest consumption
	Cluster 3	74.59	80.13	Lower consumption than Cluster 1, possible availability of food other than rice
Rice Price (IDR per kg)	Cluster 1	16,429	16,407	Medium price, reflecting national average price
	Cluster 2	26,575	26,575	Most expensive price
	Cluster 3	16,257	16,650	Medium price, reflecting national average price
Rice Production (Tons)	Cluster 1	452,133	722,592	Moderate production, most provinces
	Cluster 2	63,913	63,913	Very low production
	Cluster 3	5,098,766	4,925,948	Highest production
Population (people)	Cluster 1	6.5 million	6.5 million	Medium population

Cluster 2	2.1 million	1.4 million	Small population
Cluster 3	37 million	50 million	Largest population

Based on the previously mentioned data, the USDA states that total rice consumption in Indonesia reaches 36.5 million tons, while BPS estimates national rice production at 30.62 million tons. From this comparison, it can be concluded that Indonesia has a rice deficit of 5.88 million tons, which may have to be met through imports or other food security policies.

The clustering results show that both K-Means and HAC successfully form 3 (three) clusters, with relatively similar patterns, but have differences in the data segmentation approach:

1) In terms of rice consumption, both methods show that Cluster 2 has the lowest consumption, which includes provinces such as Central Papua and Papua Mountains, the conclusion can be drawn for cluster 2 areas either there are many other food sources besides rice or it is difficult to get rice.
2) In terms of rice prices, the K-Means and HAC methods show similar price differences. The price of rice in cluster 2 areas is very expensive, which may refer to the previous point on rice consumption that there is difficulty in obtaining rice, resulting in high demand and low availability.
3) In terms of rice production, Cluster 3 in both methods reflects the provinces with the highest rice production (West Java, Central Java, and East Java), while Cluster 2 has the lowest production, indicating areas that have little agricultural land and depend on supplies from other areas.
4) In terms of population, K-Means is more accurate in reflecting the population distribution, where Cluster 3 includes the provinces with the largest population (West Java, Central Java, and East Java), while HAC only includes one province, West Java.

K-Means more accurately reflects the population distribution, where Cluster 3 includes provinces with the largest population such as West Java, Central Java and East Java. Meanwhile, HAC only includes West Java in Cluster 3, indicating a lack of precision in grouping provinces with large populations. In addition, HAC tends to produce clusters with higher variation in rice production, as seen in Cluster 1 which has greater production than K-Means. Overall, K-Means is more effective in describing the distribution of population and rice production, while HAC shows weaknesses in segmenting high-population provinces.

Conclusions

This study advances the field of food security analysis by demonstrating how unsupervised machine learning techniques specifically K-Means Clustering and Hierarchical Agglomerative Clustering (HAC) can be applied to objectively classify Indonesian provinces based on key indicators such as rice consumption, price, production, and population. The dual-method approach highlights that while HAC offers stronger differentiation in regions with extreme price levels, K-Means excels in revealing underlying patterns in rice distribution and production across regions. By bridging spatial disparities in food-related indicators, the clustering outcomes offer a scientifically grounded foundation for more precise, data-driven policy interventions in rice distribution, price stabilization, and production planning. This work shifts the focus from descriptive national-level statistics to actionable regional segmentation, thus enhancing the capacity of decision-makers to implement targeted and equitable food security strategies. Future extensions of this research could integrate additional dimensions such as weather variability, transportation infrastructure, and supply chain logistics to further refine the clustering model and support the design of more adaptive, resilient, and sustainable food policies.

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