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A novel application of the EWMA Wilcoxon signed-rank control chart in the animal feed industry

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Abstract: Control charts are essential tools in analysis and decision-making for quality control in production processes. This study aims to develop and evaluate the performance of the Exponentially Weighted Moving Average (EWMA) Wilcoxon Signed-Rank nonparametric control chart in monitoring the fat content of animal feed products, specifically at PT Japfa Comfeed Indonesia Tbk Makassar Unit. This study introduces the EWMA Wilcoxon Signed-Rank method as a nonparametric alternative to address the limitations of the classical EWMA, which relies on the assumption of normal distribution. A comparison was conducted with the EWMA Sign control chart to assess its effectiveness in detecting process anomalies with λ parameter variations of 0.05, 0.3, and 0.8. The results indicate that the EWMA Wilcoxon Signed-Rank control chart demonstrates superior anomaly detection capability compared to the EWMA Sign control chart for all tested λ values. This method is more effective in identifying small changes in the animal feed production process. The conclusion of this study is that the EWMA Wilcoxon Signed-Rank control chart has proven to be a more reliable tool for quality control in the animal feed industry. Implementing this method can enhance accuracy in detecting process deviations, thus helping companies maintain product quality consistency.

Keywords: *Animal feed quality monitoring, EWMA Wilcoxon signed-rank control chart, Fat content anomaly detection, Nonparametric statistical process control, Small shift detection in non-normal data.*

1. Introduction

Statistical Process Control (SPC) is a problem-solving approach that uses statistical techniques to track, manage, and evaluate the manufacturing process from the point of receiving raw materials to the point of reaching customers [1] One tool that can be used to support analysis and decision-making is a control chart [2]. The $\bar{X}$ control chart, first presented by Shewhart [3] was the control chart initially employed to track process averages. According to Nuraviva, et al. [4] the weakness of the, so that the control chart $\bar{X}$ is less sensitive in detecting relatively small process shifts. To efficiently detect or monitor little changes in process averages, an exponentially weighted moving average (EWMA) control chart was created [5]. Compared to $\bar{X}$ control charts, exponentially weighted moving average (EWMA) control charts can identify out-of-control signals faster because they make use of information from prior sample data [6].

In general, EWMA control charts assume the data is normally distributed [7]. However, some studies show that EWMA charts lack robustness if the data deviates from a normal distribution. When the assumption of normality is not met, control charts produce inaccurate results and give false signals. This necessitates the use of control charts based on nonparametric statistics or nonparametric control charts. Yang, et al. [8] have suggested a nonparametric EWMA sign control chart to monitor small process mean changes from a predefined target value on non-normally distributed data [9] or for the deviation process [1]. Previous research conducted by Ainun [10] used the EWMA control chart with a nonparametric approach with the nonparametric EWMA Sign method. Meanwhile, [11] stated that

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the EWMA Signed-Rank nonparametric control chart works more effectively for use in monitoring relatively small process averages. Ali, et al. [7] the researchers designed the EWMA sign nonparametric control chart based on the sampling technique on rank and applied it in the industrial field and proposed a control chart without distribution assumptions to monitor the median of a process based on the sign test statistic. According to Abid, et al. [12] when it is assumed that the data is not normally distributed, the EWMA Wilcoxon Signed-Rank nonparametric control chart is more effective and sensitive in tracking relatively modest changes in the mean or process average.

The urgency of this research lies in the industry's need to have a more effective tool in controlling the quality of the production process, especially when the data is not normally distributed. The use of EWMA Wilcoxon Signed-Rank nonparametric control charts offers a more robust and accurate solution than previous methods. In this context, this research is important to ensure that the production process remains in control, thereby improving efficiency and the quality of the final product.

The sophistication and novelty of this research are reflected in the innovative application of nonparametric methods. The EWMA Wilcoxon Signed-Rank nonparametric control chart has not been widely applied in industry, especially in Indonesia. This study applies the method to fat content data in animal feed products at PT Japfa Comfeed Indonesia Tbk Makassar Unit, which is a new application and makes a significant contribution in the field of quality control. Some research related to this data using statistical process control is the EWMA signed control chart [10] which states that for this data the EWMA signed control chart is more sensitive to changes in the mean than the Shewhart signed control chart, while Iswan, et al. [13] applied this data using the Shewhart signed and Wilcoxon signed rank control charts whose results stated that they were more sensitive using the Wilcoxon signed rank control chart.

The purpose of this study is to apply The EWMA Wilcoxon Signed-Rank nonparametric control chart on fat content data contained in animal feed products at PT Japfa Comfeed Indonesia Tbk Makassar Unit.

2. Material and Methods

2.1. Data

The data used in this study are secondary data obtained from a thesis with the title "Nonparametric Control Chart Performance Exponentially Weighted Moving Average Sign on Animal feed Production", namely production data on animal feed PT. Japfa Comfeed Indonesia, Tbk Makassar Unit. The animal feed product inspection data used is variable data on the percentage of fat content in animal feed products from December 2021 to January 2022. The data consists of 30 samples of animal feed products with 10 observations on the fat content contained for each product sample.

Table 1.
Observation Data of Fat Content (%) in Animal Feed Products from December 2021 to January 2022.

Sample of animal feed product (i)	Observation of Fat Content (%) in Animal Feed Products (j)									
	x1	**x2**	**x3**	**x4**	**x5**	**x6**	**x7**	**x8**	**x9**	**x10**
1	5.8	5.7	5.9	5.3	6	5.9	5.5	5.8	5.2	5
2	5.1	4.7	5.2	5	5.8	5.7	4.9	5	5.2	5.5
3	5.7	5.5	5.9	6.1	5.8	5.5	5.2	4.9	5.3	5.8
4	5.6	5.7	5.6	5.5	6.4	5.8	6.2	5.9	5.2	5.5
5	6.7	6.3	6	5.8	5.7	5.3	5	5.5	5.3	5.9
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
26	6	5.9	6.3	6.4	6.7	6.5	6.4	6	6.5	6.6
27	5.8	5.5	5.6	4.9	5.5	5.8	4.7	5.9	5.8	5.5
28	5.7	5.9	6.3	6.2	6	5.9	5.9	5.7	5.9	6
29	5.7	5.8	6.1	5.7	5.8	6.1	6.4	6.3	6.2	6.4
30	5.5	5.2	5.3	5.1	5.3	5.5	5.4	5.9	5.4	5.8

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2.2. Control Chart

To keep track of or manage whether a process is subject to statistical quality control or not, control charts are utilized. Thus, it can resolve issues and result in improvements in quality [14]. The general form of the control chart in equations (2.1), (2.2) and (2.3) is as follows [15]:

$$UCL = \mu + K\sigma \tag{1}$$

$$CL = \mu \tag{2}$$

$$LCL = \mu - K\sigma \tag{3}$$

where μ and σ are the corresponding means and standard deviations of the applied quality statistics. K is the control limit parameter in the meantime.

2.3. Test Assumption

Assumption testing is a process for testing whether the assumptions underlying an analysis or statistical model have been met or not. Making sure the data to be examined satisfies the assumptions needed by the specific statistical approach to be employed is the goal of the assumption test [10]. The assumption tests on the control chart consist of a normality test and a data randomness test (run test).

2.3.1. Normality Test

The purpose of the normality test is to determine if a variable is normally distributed or not, as well as to evaluate the distribution of data within a set of data [16] One normality test that can be used is the Kolmogrov-Smirnov test. The test statistics in equations (2.4) and (2.5) are as follows [17]:

Hipotesis:

H_0 : data is normally distributed

H_1 : data is not normally distributed

Test statistics:

$$D_{hitung} = max|F_s(x) - F_t(x)| \tag{4}$$

$$F_s(x) = \frac{f_{kum}}{n} \tag{5}$$

with:

$F_s(x)$: cumulative frequency distribution of the data

$F_t(x)$: cumulative probability of normal distribution for each observed value

D_{hitung} : maximum deviation

f_{kum} : cumulative frequency i-th

n : number of data

Level of Significance:

$\alpha = 0{,}05$

Testing Criteria:

If the calculated $D_{count} < D_{\alpha,n}$ (value $\alpha = 0{,}05$), then H_0 is accepted, which means that the data distribution is normally distributed. On the other hand, if the calculated $D_{count} > D_{\alpha,n}$ (nilai $\alpha = 0{,}05$), hen there is not enough evidence to accep H_0 which means that the data used is not normally distributed.

2.3.2. Run Test

The data randomness test (run test) is used to test whether the observation data is a random distribution or not [8]. The hypothesis tests for randomness tests (run tests) are:

Hypothesis:

H_0 : data is random

H_1 : data is not random

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Test Statistic:

$$Z_{count} = \frac{r - \mu_r}{\sigma_r} \tag{6}$$

with r having a normal distribution with the average value (μ_r) and standard deviation (σ_r) obtained from the following calculations:

$$\mu_r = \frac{2n_1n_2}{n_1n_2} \tag{7}$$

$$\sigma_r = \sqrt{\frac{2n_1n_2(2n_1n_2 - n_1 - n_2)}{(n_1 + n_2)^2(n_1 + n_2 - 1)}} \tag{8}$$

with:
n_1 : number of data marked (+)
n_2 : number of data marked (-)
r : number of runs
Level of Significance:
$\alpha = 0{,}05$
Test criteria:
H_0 is accepted if $-\frac{Z_\alpha}{2} < Z_{count} < \frac{Z_\alpha}{2}$
H_0 is rejected if the value of $Z_{count} < -\frac{Z_\alpha}{2}$ atau $Z_{count} > \frac{Z_\alpha}{2}$

2.4. Control Chart EWMA

Roberts [18] originally presented the EWMA (Exponentially Weighted Moving Average) control chart in 1959 [19]. Exponentially Weighted Moving Average (EWMA) control charts are a kind of control charts that are used to identify changes in the average-average and to control continuous and quantitative variable data [20]. To determine the moving average from the EWMA control chart, equation (2.9) is used as follows [4]:

$$Z_i = \lambda X_i + (1 - \lambda)_{Z_{i-1}} \tag{9}$$

with:
Z_i : EWMA moving average on the i -th sample ($i = 1,2,3, \dots, m$)
λ : weighting parameter with value $0 < \lambda < 1$
X_i : observation value at time i
The control limits on the EWMA control chart in equations (2.10), (2.11) and (2.12) are as follows:

$$UCL = \mu_0 + K\sigma\sqrt{\frac{\lambda}{2 - \lambda}[1 - (1 - \lambda)^{2i}]} \tag{10}$$

$$CL = \mu_0 \tag{11}$$

$$LCL = \mu_0 - K\sigma\sqrt{\frac{\lambda}{2 - \lambda}[1 - (1 - \lambda)^{2i}]} \tag{12}$$

with:
μ_0 : $\bar{X} = \frac{\sum_{i=1}^{m} \bar{X}_i}{m}$
σ : standard deviation
K : control limit parameter

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Vol. 9, No. 5: 1324-1337, 2025
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CL : *Center Line* EWMA
UCL : *Upper Control Limit*
LCL : *Lower Control Limit*
λ : weighting parameter with value $0 < \lambda < 1$

2.5. EWMA Wilcoxon Signed Rank Control Chart nonparametric

The nonparametric Wilcoxon Signed-Rank (EWMA) control chart is a tool for identifying comparatively tiny changes in the process average [11]. For example X_{ij}, $i = 1,2,3, \dots m$ and $j = 1,2, \dots, n$, where X_{ij} is a variable that shows the j-th in the i-th subgroup with size $n > 1$. For example R_{ij}^{+} represents the rank of the absolute value, namely the difference of the pair of observations $|X_{ij} - M_0|$, $j = 1,2, \dots n$, in the ith sample. Defined in equation (2.13) as follows:

$$SR_i = \sum_{j=1}^{n} sign(X_{ij} - M_0) R_{ij}^{+} \tag{13}$$

with

$$sign(X_{ij} - M_0) = \begin{cases} -1, & if\ X_{ij} < M_0 \\ 0, & if\ X_{ij} = M_0 \\ 1, & if\ X_{ij} > M_0 \end{cases}$$

Let SR_i is a random variable that expresses the sum of absolute values with positive and negative differences. In general, statistics presented in (2.13) can be expressed in equation (2.14) as follows:

$$SR_i = 2R^{+} - \frac{n(n+1)}{2} \tag{14}$$

where R^{+}s the number of positively signed ranks. The EWMA signed−rank nonparametric control chart is created by accumulating the statistics of $SR_1, SR_2, SR_3, \dots$ successive subgroups. The formula for determining the EWMA Signed-Rank nonparametric plot point using equation (2.15) is as follows:

$$Z_i = \lambda(SR_i) + (1 - \lambda) Z_{i-1} \tag{15}$$

with:
Z_i : EWMA Signed-Rank nonparametric plot point value in the i-th sample
λ : weighting parameter ($0 < \lambda < 1$)
Z_{i-1} : EWMA Signed-Rank nonparametric plot point value on the sample previous $(i - 1)$

where the value $Z_0 = E(SR_i)$ is the average of SR_i. Expectation values and variance values are required to compute the control limits from the EWMA Signed-Rank control chart. As a result, equations (2.16) and (2.17) are produced as follows:

$$E(SR_i) = 0 \tag{16}$$

The EWMA signed-rank nonparametric control chart's control limits can be represented as follows in equations (2.17), (2.18), and (2.19).

$$UCL = +K \sqrt{\left(\frac{n(n+1)(2n+1)}{6}\right)\left(\frac{\lambda}{2-\lambda}(1 - (1-\lambda)^{2i})\right)} \tag{17}$$

$$CL = 0 \tag{18}$$

$$LCL = -K \sqrt{\left(\frac{n(n+1)(2n+1)}{6}\right)\left(\frac{\lambda}{2-\lambda}(1 - (1-\lambda)^{2i})\right)} \tag{19}$$

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Vol. 9, No. 5: 1324-1337, 2025
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with:
λ : weighting parameter
K : control limit parameter

The K value can be determined based on the number of samples (n) and the weighting parameters (λ) used based on recommendations from Yang, et al. [8] under the condition $ARL \approx 370.$

2.6. ARL EWMA Wilcoxon Signed Rank Control Chart Nonparametric

Finding the change in the process that has gone out of control as soon as feasible is the primary goal of statistical process control charts. Average Run Length is one method [21]. Average Run Length (ARL) is the average number of sample points drawn before one point shows an uncontrolled condition. ARL is divided into 2 namely ARL_0 (ARL in control) and ARL_1 (ARL out of control) using equations (2.20) and (2.21) as follows:

$$ARL_0 = \frac{1}{p(reject\ H_0|H_0\ is\ true)} = \frac{1}{\alpha} \tag{20}$$

$$ARL_1 = \frac{1}{1 - p(accept\ H_0|H_0\ is\ false)} = \frac{1}{1-\beta} \tag{21}$$

H_0 is a process in a controlled condition (in control) with the value α being the probability of a type I error, namely stating that the process is in a state of uncontrollability (out of control) but in reality, the process is in a state of control (in control). Meanwhile, β s the probability of a type II error, namely stating that the process is in a state of control (in control) even though the process is in a state of uncontrollability (out of control). So ARL_0 is the number of sample points depicted before the point indicating an out-of-control condition when the process is in control. Meanwhile ARL_1 can be interpreted as the average of observation points plotted until uncontrolled observations are found (out of control) [10].

The ARL_0 alue used is similar to the approach used by the EWMA Sign nonparametric control chart, namely, based on recommendations from Yang et al., (2011) under the condition $ARL \approx 370$, using a Markov chain approach. The algorithm is to use equation (2.22) as follows [22] as follows:

$$\boldsymbol{ARL = (Q^t \times 1)^t((I - Q)^{-1}1)} \tag{22}$$

with:
$\boldsymbol{Q}$: *transition probability matrix*
$\boldsymbol{I}$: *identity matrix*

3. Result and Discussion

3.1. EWMA Wilcoxon Signed Rank Control Chart Nonparametric

The initial step taken to create a nonparametric EWMA Wilcoxon signed rank control chart is to sort the data first, then determine the median value (M_0) of all samples with $n = 300$. Because the amount of data used is even data M_0 is obtained in the following way:

$$\begin{aligned} M &= \frac{n+1}{2} \\ &= \frac{300+1}{2} \\ &= 150{,}5 \end{aligned} \tag{23}$$

From the value obtained in equation (3.1), it is found that the median value is between the order of 150 and 151. With the order value of $150 = 5{,}8$ and the order value of $151 = 5{,}8$ he median value (M_0) is obtained in equation (3.2) as follows:

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$$M_0 = \frac{5,8 + 5,8}{2} = 5,8 \quad (24)$$

The median value obtained will be used to colculate the value of $D_i = X_i - M_o$, the results of D_i values will be sorted form smallest to largest for each $i = 1,2,3 \dots 30$ based on their absolute value and give from 1to n with n is the number D_i that is not zero. So, we get R_{ij}^{+} for every $i = 1,2,3 \dots 30$ and $j = 1,2 \dots 10$. Observasion results D_i and R_{ij}^{+} can be seen in the attachment 5. The next steps are to determine the value of the weighting parameter λ $(0 < \lambda < 1)$ and the parameter value k as determinants of the width of the EWMA *Wilcoxon Signed Rank nonparametric control chart*. The k value is determined based on the number of samples (n) and the weighting parameter (λ) used based on recomendations from Yang, et al. [8] under the condition $ARL_0 \approx 370$. The following are the results of the UCL and LCL calculations based on the λ and k values to determine the parameter values to be used using equation (2.17) dan (2.19).

Table 2.
UCL and LCL Calculation Results Based On $\boldsymbol{\lambda}$ And $\boldsymbol{k}$ Values.

$\boldsymbol{\lambda}$	$\boldsymbol{k}$	**UCL**	**LCL**
0.05	2.49	7.823434	-7.82343
0.1	2.69	12.10893	-12.1089
0.15	2.77	15.4764	-15.4764
0.2	2.84	18.57494	-18.5749
0.25	2.86	21.21033	-21.2103
0.3	2.86	23.57396	-23.574
0.4	2.89	28.35295	-28.3529
0.5	2.88	32.62588	-32.6259
0.6	2.86	36.73737	-36.7374
0.7	2.85	41.03482	-41.0348
0.8	2.81	45.0185	-45.0185

Table 2 illustrates that the width of the difference between the upper and lower control charts increases with increasing λ value. Therefore, the λ values that will be used in this research are 0.05, 0.3 and 0.8 which respectively represent small, medium and large change values. Meanwhile, when determining the value of k following the recomendations of Yang, et al. [8] under the condition $ARL_0 \approx 370$ with a total of $n = 10$ the value of $K = 2.49$ for $\lambda = 0.05$, the value of $k = 2.86$ for $\lambda = 0.3$ and the value of $k = 2.81$ for $\lambda = 0.8$. the results of the SR_i, the initial value (Z_0), the weighting parameter (λ) and the control chart parameter (k) will be used to calculate the value of the plot points Z_i. Searching for the value of each Z_i statistic on each plot can be done using equation (2.18) with the value $Z_0 = E(SR_i) = 0$. As is known, the value of each statistic Z_i is interrelated, namely the statistical value Z_1 is needed to find the statistical value Z_2, and so on until you get the statistical value Z_{30}.

The following is a nonparametrik control chart EWMA *Wilcoxon Signed Rank* to monitor process averages on observation data of fat composition in animal fees products for each value of $\lambda = 0.05$, $\lambda = 0.3$ and $\lambda = 0.8$ using equation (2.17), (2.18) and (2.19).

ISSN: 2576-8484
Vol. 9, No. 5: 1324-1337, 2025
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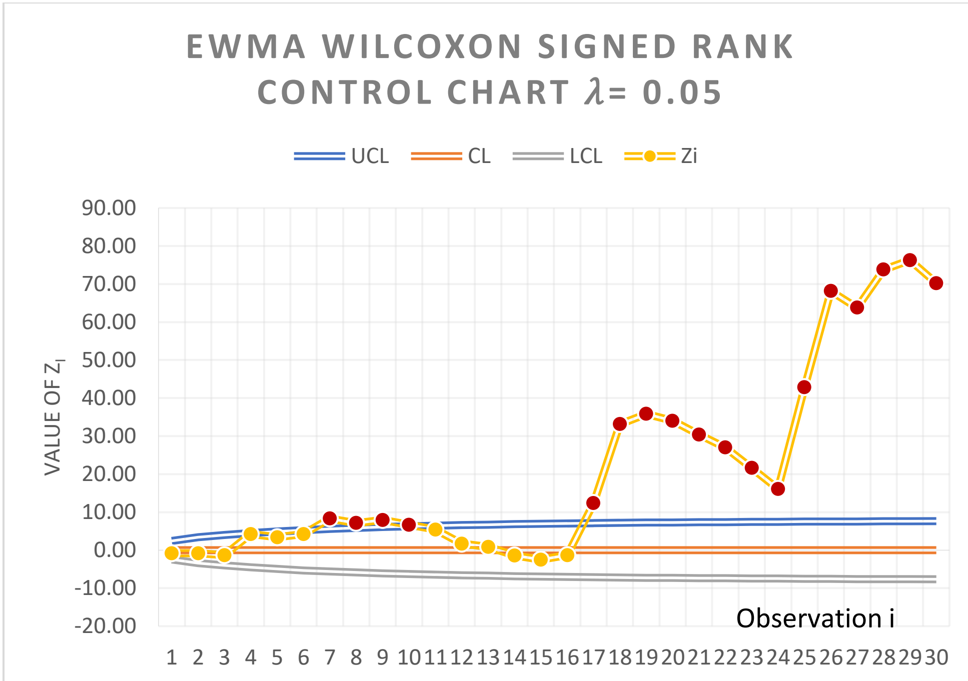

Figure 1.
EWMA Wilcoxon Signed Rank Nonparametric Control Chart for $\lambda = 0.05$.

Figure 1 shows that the limits of the EWMA *Wilcoxon Signed Rank nonparametric control chart* with $\lambda = 0.05$ vary with the upper control chart ranging from 2.442866 to 7.641097, the lower control chart ranging from -2.442866 to -7.641097 and with the middle limit being 0. Controlling the quality of fat composition in feed products livestock for $\lambda = 0.05$ indicates that the process is in an uncontrolled state or there is *out of control*. There are 18 plot points that are outside the control chart, plot points 7, 8, 9, 10, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and plot 30.

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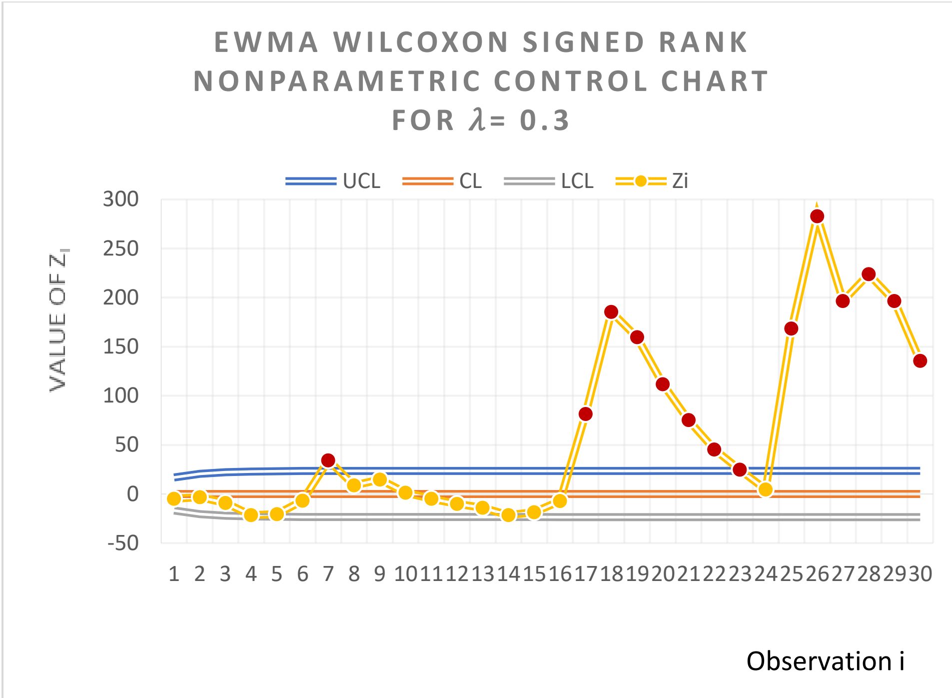

Figure 2.
EWMA Wilcoxon Signed Rank Nonparametric Control Chart for $\boldsymbol{\lambda = 0.3}$.

Figure 2 shows that the limits of the EWMA *Wilcoxon Signed Rank nonparametric control chart* with $\lambda = 0.3$ vary with the upper control chart ranging from $16{,}83518$ to $23{,}57396$, the lower control chart ranging from $-16{,}83518$ to $-23{,}57396$ and with the middle limit being 0. Controlling the quality of fat composition in feed products livestock for $\lambda = 0.3$ indicates that the process is in an uncontrolled state or there is *out of control*. There are plot points that are outside the control chart, plot points 7, 17, 18,19, 20, 21, 22, 23, 25, 26, 27, 28, 29 and plot 30.

Figure 3 shows the EWMA Wilcoxon Signed-Rank Nonparametric Control Chart with parameter λ = 0.8, which is used to monitor the stability of a process. The value of the Zi statistic reflects the fluctuations in the monitored process. Most of the Zi values are within the control limits, indicating that the process is generally stable. However, some red dots above the UCL signify significant deviations in the process, which require further analysis. The points that exceed the control limits occur mainly in observations 7, 17, 18, 19 25, 26, 27, 28 and 29, indicating a significant difference compared to the process average. This could be due to external factors such as changes in raw materials, procedural errors, or uncontrolled variations in the production system. With these deviations, an in-depth evaluation is required to identify the root cause and implement corrective actions to maintain production stability and quality. Overall, this graph shows that although the process is generally under control, there are indications of anomalies that need to be watched out for and further controlled.

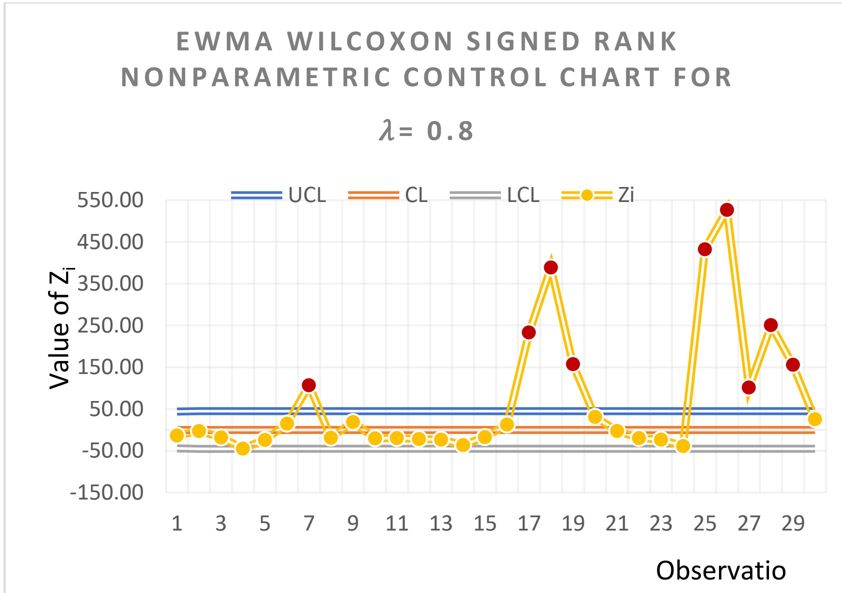

Figure 3.
EWMA Wilcoxon Signed Rank Nonparametric Control Chart for $\boldsymbol{\lambda = 0.8}$.

3.2. ARL Nonparametric Control Chart EWMA Wilcoxon Signed Rank

The *Average Run Length* (ARL) value on the EWMA *Wilcoxon Signed Rank control chart* is obtained using equation (2.22) to find the ARL value using a *Markov Chain* approach formed based on a transition matrix with elements $p_{i,j}$ that follow a normal distribution. Using the *software* R attached in appendix 11, the matrix elements obtained. ARL values for several λ values can be seen in Table 3 as follows:

Table 3.
EWMA based nonparametric ARL values λ.

$\lambda = 0.05$ $k = 2.49$	2.455
$\lambda = 0.1$ $k = 2.61$	3.379
$\lambda = 0.3$ $k = 2.86$	0.991
$\lambda = 0.5$ $k = 2.88$	0.576
$\lambda = 0.8$ $k = 2.81$	0.172

Source: Data Processing Result, 2024.

Table 3 presents the Average Run Length (ARL) values based on the EWMA nonparametric method for different values of λ and k. The parameter λ in EWMA functions as a smoothing factor, where a smaller λ results in stronger smoothing (slower response to changes), while a larger λ makes the chart more sensitive to small variations in the data. The parameter k represents the control limit constant used in quality monitoring processes. From the table, it is observed that ARL values tend to decrease as λ increases. At λ = 0.05, the ARL value is relatively high (2.455), indicating that the system requires more observations before detecting an anomaly, meaning lower detection sensitivity. Conversely, at λ = 0.8, the ARL value drops significantly to 0.172, suggesting that the chart detects process changes more quickly. This indicates that the choice of λ significantly affects the balance between sensitivity and stability in nonparametric EWMA-based quality control. If the goal is to detect changes as quickly as possible, a larger λ may be preferable. However, if reducing false alarms is a priority, a smaller λ would be more effective.

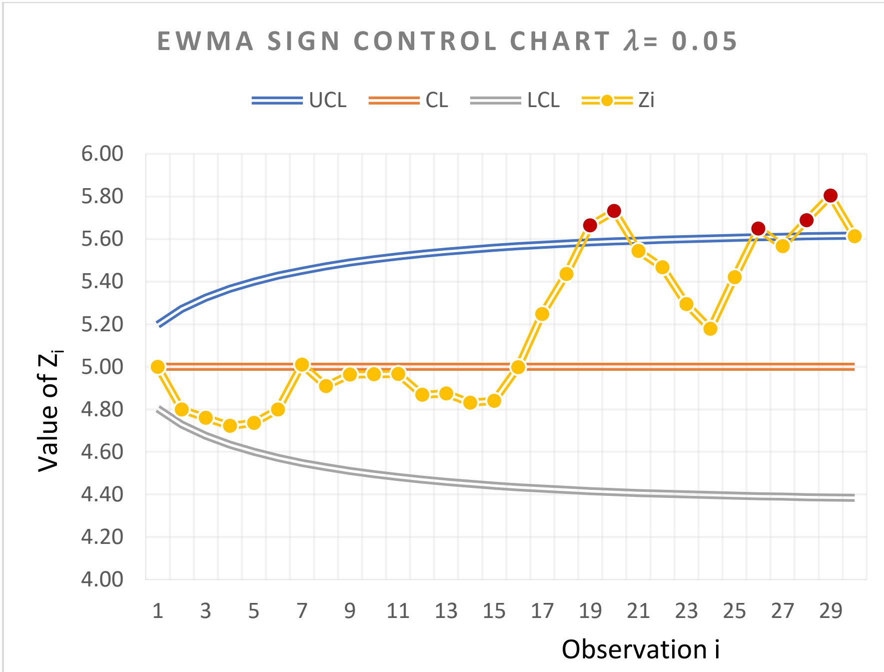

Figure 4.
EWMA *Signed Rank* Nonparametric Control Chart for λ= 0.05.

Figure 4 shows the EWMA Sign nonparametric control chart for λ= 0.05 only detected 5 out of control signals, namely the 19, 20, 26, 28 and 29. Meanwhile, based on Figure 5 The EWMA Wilcoxon Signed Rank nonparametric control chart detected 18 out of control signals, namely plot points 7, 8, 9, 10, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30. This shows that the EWMA Wilcoxon Signed Rank nonparametric control chart is more sensitive at identifying out-of-control signals in the fat content data of animal feed items. This is because the EWMA Wilcoxon Signed Rank nonparametric control chart detects more out of control signals than the EWMA Sign nonparametric control chart.

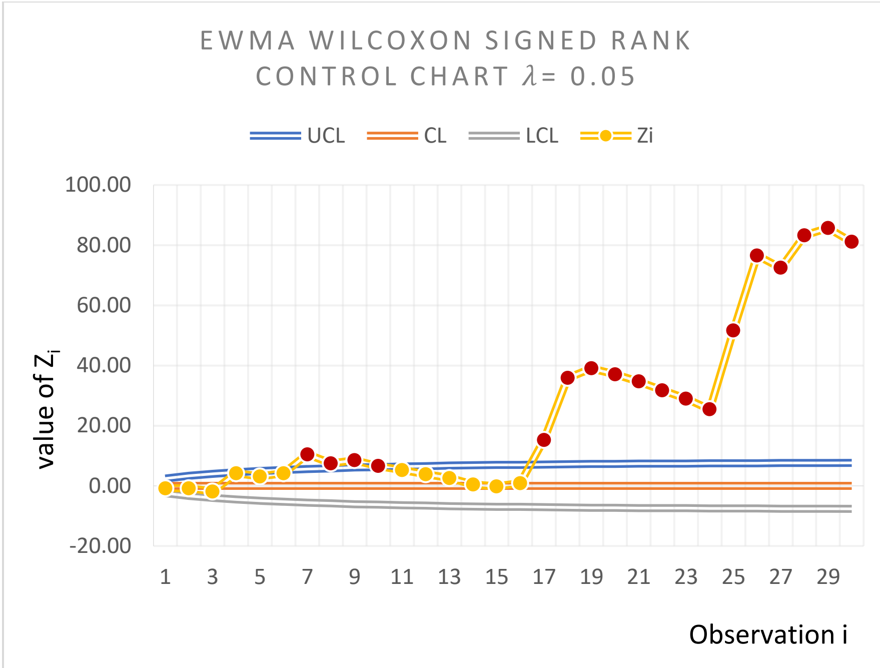

Figure 5.
EWMA *Wilcoxon Signed Rank* Nonparametric Control Chart λ= 0.05.

4. Conclusion

Based on the results and discussions, it can be concluded that the EWMA Wilcoxon Signed-Rank nonparametric control chart is an effective tool for detecting process shifts in the quality control of animal feed products. The findings indicate that the process is uncontrolled, as evidenced by 18 out-of-control points for $\lambda = 0.05$, 14 points for $\lambda = 0.3$, and 9 points for $\lambda = 0.8$, suggesting potential issues in the production process. These results confirm the effectiveness of the EWMA Wilcoxon Signed-Rank control chart in identifying process anomalies, reinforcing its value as a critical component of quality assurance in the animal feed manufacturing industry. The ability of this control chart to detect outliers and signal potential abnormalities highlights its importance in ensuring product consistency and regulatory compliance. Its implementation can assist companies in identifying and addressing production issues early, thereby enhancing efficiency and reducing the risk of defective products.

However, this study has several limitations. First, the research was conducted on a single product type (animal feed), which limits the generalizability of the results to other products. Second, the dataset was obtained from a single production unit at PT Japfa Comfeed Indonesia Tbk, restricting the external validity of the findings. Therefore, future research should explore the application of the EWMA Wilcoxon Signed-Rank control chart across different product types and production units to assess its broader applicability. Additionally, investigating its performance under various production conditions and data distribution scenarios would help evaluate its robustness. Further studies could also integrate this method with other quality control techniques to explore potential synergies and efficiency improvements in quality monitoring. Thus, the integration of the EWMA Wilcoxon Signed-Rank nonparametric control chart into quality assurance protocols is strongly recommended for organizations committed to maintaining excellence in product quality and market competitiveness

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