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Research Article

Statistical Analysis for Food Quality in the Presence of Vague Information

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The present study introduces the neutrosophic statistical test to see investigate the difference between variances of two populations when correlation exits in pair observations. The procedure and statistic of the proposed test under neutrosophic statistics are introduced in the paper. The application of the proposed test is given using the food industry data. The efficiency of the proposed test is compared with that of the existing test in terms of the measure of indeterminacy, flexibility, and information. From the real application and comparative studies, it is concluded that the proposed test is quite reasonable to apply in uncertainty.

1. Introduction

The F-test is applied for testing the equality of two population variances under the assumption that the data are obtained from the normal distribution. Usually, the *F*-tests are applied under the assumption that the data are independent and obtained from the normal distribution [1]; we also discussed the application of the *F*-test when the pair data are correlated. This *F*-test is applied to investigate the significant difference between the equality of two population variances with correlated pair data [2–4]. More applications about the statistical tests can be seen in [4–8] where the applications of statistical tests in various practical fields are provided.

Classical statistics-based tests cannot be applied to the observations in the data which are fuzzy, in intervals, and uncertain. The fuzzy-based tests are the alternative of classical statistical tests in these situations. As mentioned in [9], "statistical data are frequently not precise numbers but more or less nonprecise, also called fuzzy. Measurements of continuous variables are always fuzzy to a certain degree." The authors of [10–22] worked on various types of the statistical tests using fuzzy logic.

The statistical tests based on fuzzy logic do not give information about the measure of indeterminacy. To overcome this shortcoming [23], we introduced neutrosophic logic as an extension of fuzzy logic. The efficiency of the neutrosophic logic over fuzzy analysis and interval-based analysis was discussed in [24]. Recently, several applications of the neutrosophic logic were discussed in [25–30] and neutrosophic statistics were introduced as an extension of classical statistics. For more details on the neutrosophic statistics, see https://archive.org/details/neutrosophic-statistics?tab=about, https://archive.org/details/neutrosophic-statistics?tab=collection and http://fs.unm.edu/NS/NeutrosophicStatistics.htm. The efficiency of neutrosophic statistics over classical statistics was proven in [31–37].

The existing F-test for testing the equality of variances for correlated data under classical statistics cannot be applied in the presence of imprecise data. By exploring the literature and to the best of our knowledge, we did not find any work on the *F*-test for testing the equality of variances for correlated data under neutrosophic statistics. In this paper, the work when observations are correlated under neutrosophic statistics will be presented. The operational procedure of the proposed test will be given for testing the hypothesis of equality of two variances. The application of the proposed test will be given in the data taken from the food industry. It is expected that the proposed test will be efficient than the existing test in terms of information, flexibility, and adequacy.

2. The Proposed *F*-Test for Variances with Correlated Data

As mentioned before, the existing F-test for two population variances when pair data are correlated can be applied only when all observations are determined, certain, and exact. In this section, the F-test for two population variances when pair data are correlated will be introduced when the data is an interval, indeterminate, and neutrosophic. The main objective of the proposed test is to investigate the difference between two pupation variances when the data are paired and have a correlation. In addition, it is assumed that the data follow the neutrosophic normal distribution. Let σ_{1N}^2 and σ_{2N}^2 be the neutrosophic variances of the first and the second population, respectively. The proposed test will be applied for testing the null hypothesis. The proposed test will be applied for testing the null hypothesis H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ vs. the alternative hypothesis H_1: $\sigma_{1N}^2 \neq \sigma_{2N}^2$. Suppose that $\{X_{1N} = X_{1L} + X_{1U}I_{1N};\ I_{1XN} \in [I_{1XL}, I_{1XU}], Y_{1N} = Y_{1L} + Y_{1U}I_{1N}; I_{1YN} \in [I_{1YL}, I_{1YU}]\}, \ldots, \{X_{nN} = X_{nL} + X_{nU}I_{nN}; I_{nXN} \in [I_{nXL}, I_{nXU}],\ Y_{nN} = Y_{nL} + Y_{nU}I_{nYN}; I_{nYN} \in [I_{nYL}, I_{nYU}]\}$ is a pair of neutrosophic observations of neutrosophic sample size $n_N \in [n_L, n_U]$. Note that $X_{1L}, \ldots, X_{nL}$ and $Y_{1L}, \ldots, Y_{nL}$ are the determined part of pair observations and $X_{1U}I_{1N}, \ldots, X_{nU}I_{nXN}$ and $Y_{1U}I_{1N}, \ldots, Y_{nU}I_{nYN}$ are the indeterminate part of the same pair observations. Note also that $I_{nXN} \in [I_{nXL}, I_{nXU}]$ and $I_{nYN} \in [I_{nYL}, I_{nYU}]$ are measures of indeterminacy associated with the neutrosophic pair observations. Based on the information and by following the work in [35, 36], the neutrosophic means are defined as

$$\begin{aligned}\overline{X}_{iN} &= \overline{X}_L + \overline{X}_U I_{XN}; I_{XN} \in [I_{XL}, I_{XU}]; \quad i = 1, 2, 3, \ldots, n_N,\\ \overline{Y}_{iN} &= \overline{Y}_L + \overline{Y}_U I_{YN}; I_{YN} \in [I_{YL}, I_{YU}]; \quad i = 1, 2, 3, \ldots, n_N.\end{aligned} \tag{1}$$

The neutrosophic variances are defined as

$$\begin{aligned}S_{XN}^2 &= \frac{\sum_{i=1}^{n_N} \left(X_{iN} - \overline{X}_{iN}\right)^2}{n_N}; \quad n_N \in [n_L, n_U], \overline{X}_{iN} \in [\overline{X}_{iL}, \overline{X}_{iU}],\\ S_{YN}^2 &= \frac{\sum_{i=1}^{n_N} \left(Y_{iN} - \overline{Y}_{iN}\right)^2}{n_N}; \quad n_N \in [n_L, n_U], \overline{Y}_{iN} \in [\overline{Y}_{iL}, \overline{Y}_{iU}],\end{aligned} \tag{2}$$

where

$$\begin{aligned}\sum_{i=1}^{n_N} \left(X_i - \overline{X}_{iN}\right)^2 &= \sum_{i=1}^{n_N} \begin{bmatrix} \min\begin{pmatrix} (X_{iL} + X_{Ui}I_L)(\overline{X}_L + \overline{X}_U I_L), (X_{iL} + X_{iU}I_L)(\overline{X}_L + \overline{X}_U I_U) \\ (X_{iL} + X_{iU}I_U)(\overline{X}_L + \overline{X}_U I_L), (X_{iL} + X_{iU}I_U)(\overline{X}_L + \overline{X}_U I_U) \end{pmatrix} \\ \max\begin{pmatrix} (X_{iL} + X_{iU}I_L)(\overline{X}_L + \overline{X}_U I_L), (X_{iL} + X_{U}I_L)(\overline{X}_L + \overline{X}_U I_U) \\ (X_{iL} + X_{iU}I_U)(\overline{X}_L + \overline{X}_U I_L), (X_{iL} + X_{iU}I_U)(\overline{X}_L + \overline{X}_U I_U) \end{pmatrix} \end{bmatrix}, \quad I_{XN} \in [I_{XL}, I_{XU}],\\ \sum_{i=1}^{n_N} \left(Y_i - \overline{Y}_{iN}\right)^2 &= \sum_{i=1}^{n_N} \begin{bmatrix} \min\begin{pmatrix} (Y_{iL} + Y_{Ui}I_L)(\overline{Y}_L + \overline{Y}_U I_L), (Y_{iL} + Y_{iU}I_L)(\overline{Y}_L + \overline{Y}_U I_U) \\ (Y_{iL} + Y_{iU}I_U)(\overline{Y}_L + \overline{Y}_U I_L), (Y_{iL} + Y_{iU}I_U)(\overline{Y}_L + \overline{Y}_U I_U) \end{pmatrix} \\ \max\begin{pmatrix} (Y_{iL} + Y_{iU}I_L)(\overline{Y}_L + \overline{Y}_U I_L), (Y_{iL} + Y_{U}I_L)(\overline{Y}_L + \overline{Y}_U I_U) \\ (Y_{iL} + Y_{iU}I_U)(\overline{Y}_L + \overline{Y}_U I_L), (Y_{iL} + Y_{iU}I_U)(\overline{Y}_L + \overline{Y}_U I_U) \end{pmatrix} \end{bmatrix}, \quad I_{YN} \in [I_{YL}, I_{YU}].\end{aligned} \tag{3}$$

Under H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$, the neutrosophic $F_N \in [F_L, F_U]$ is defined by

$$F_N = \frac{S_{YN}^2}{S_{XN}^2}; \quad F_N \in [F_L, F_U]. \tag{4}$$

The neutrosophic correlation defined by the work in [34] is given by

$$r_N = \frac{n_N \sum X_{nN} Y_{nN} - \sum X_{nN} \sum Y_{nN}}{\sqrt{\left\{n_N \sum X_{nN}^2 - \left(\sum X_{nN}\right)^2\right\}\left\{n_N \sum X_{nN}^2 - \left(\sum Y_{nN}^2\right)^2\right\}}}; \quad n_N \in [n_L, n_U]. \tag{5}$$

The neutrosophic quotient $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$ is defined by

$$\gamma_N F_N = \frac{F_N - 1}{\left[(F_N + 1)^2 - 4 r_N^2 F_N \right]}; \quad \gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]. \tag{6}$$

The neutrosophic form of $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$ can be expressed as

$$\gamma_N F_N = \gamma_L F_L + \gamma_U F_U I_{\gamma_N F_N}; \quad I_{\gamma_N F_N} \in \left[I_{\gamma_L F_L}, I_{\gamma_U F_U} \right]. \tag{7}$$

In the neutrosophic form of $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$, the first part $\gamma_L F_L$ presents the determined part and $\gamma_U F_U I_{\gamma_N F_N}$ is the indeterminate part. The proposed form of quotient reduces to classical statistics when $I_{\gamma_L F_L} = 0$. The application of the proposed test is discussed using Figure 1.

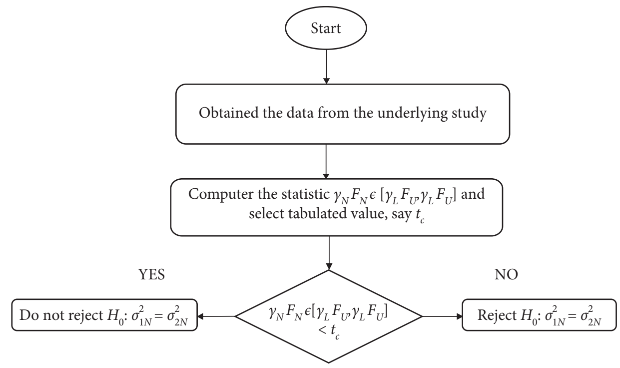

Figure 1: The operational process of the proposed test.

3. Application Using Food Data

The application of the proposed test will be given on the data collected from the food industry. To keep the quality of the food, the food inspectors test the food for different characteristics such as taste, shape, and hardness. Similar examples were discussed in [22, 38]. The evaluation of food by the inspector for product A and product B is shown in Table 1. From Table 1, it is clear that experts provide the food evaluation in indeterminate interval reporting the minimum value and the maximum value. The evaluation of food is imprecise data rather than the exact; therefore, the existing test is under classical statistics. For the data, the decision makers are interested to see whether the variances of both products have the same variances or not. Therefore, the proposed test can be applied to test H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ vs. the alternative hypothesis H_1: $\sigma_{1N}^2 \neq \sigma_{2N}^2$. The neutrosophic means for the data are given by

$$\begin{aligned} \overline{X}_{iN} &= 5.84 + 6.86 I_{XN}; \quad I_{XN} \in [0, 0.1486], \\ \overline{Y}_{iN} &= 8.26 + 9.0 I_{YN}; \quad I_{YN} \in [0, 0.0822]. \end{aligned} \tag{8}$$

The neutrosophic variances for the data are calculated as follows:

$$\begin{aligned} S_{XN}^2 &= \frac{\sum_{i=1}^{n_N} \left(X_{iN} - \overline{X}_{iN} \right)^2}{n_N} = \frac{[4.6, 11]}{10} = [0.46, 1.1], \\ S_{YN}^2 &= \frac{\sum_{i=1}^{n_N} \left(Y_{iN} - \overline{Y}_{iN} \right)^2}{n_N} = \frac{[4.904, 8.28]}{10} = [0.49, 0.828]. \end{aligned} \tag{9}$$

Under H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$, the neutrosophic $F_N \in [F_L, F_U]$ is calculated as

$$F_N = \frac{S_{YN}^2}{S_{XN}^2} = \frac{[0.49, 0.828]}{[0.46, 1.1]}; \quad F_N \in [1.135, 1.765]. \tag{10}$$

The neutrosophic correlation is calculated as $r_N \in [0.02, -0.1785]$. The neutrosophic quotient $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$ is calculated as

$$\gamma_N F_N = \frac{[1.135, 1.765] - 1}{\left[([1.135, 1.765] + 1)^2 - 4[0.02, -0.1785][1.135, 1.765] \right]}; \quad \gamma_N F_N \in [0.06, 0.28]. \tag{11}$$

The neutrosophic form of $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$ is given as

$$\gamma_N F_N = 0.06 + 0.28 I_{\gamma_N F_N}; \quad I_{\gamma_N F_N} \in [0, 0.7857]. \tag{12}$$

In the neutrosophic form of $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$, the first part 0.06 presents the determined part and $0.28 I_{\gamma_N F_N}$ is the indeterminate part, where $I_{\gamma_N F_N} \in [0, 0.7857]$ is the measure of indeterminacy associated with $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$. The proposed form of quotient reduces to classical statistics when $I_{\gamma_L F_L} = 0$. The proposed test is implemented in the following steps:

Step- 1: state H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ vs. H_1: $\sigma_{1N}^2 \neq \sigma_{2N}^2$

Step- 2: set the level of significance $\alpha = 0.05$

Step- 3: calculate $\gamma_N F_N \in [0.06, 0.28]$, and compared with the critical value from [1], it is 0.632

Step- 4: as $\gamma_N F_N \in [0.06, 0.28] < 0.632$, the null hypothesis H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ can be accepted

Table 1: The neutrosophic data.

$A = X_{iN}$	[5, 7]	[6.5, 7.5]	[5, 7]	[6, 8]	[7, 9.4]	[6.5, 8.1]	[5, 8.4]	[6, 9]	[5.4, 7.8]	[6, 8.4]
$B = Y_{iN}$	[7, 9]	[8.2, 10]	[6.5, 8.3]	[6, 8]	[5.5, 8.3]	[7, 9]	[6.4, 10]	[8, 10]	[6.8, 8.8]	[7.2, 8.6]

From the study, it is concluded that the neutrosophic variances of both food experts are the same. Therefore, there is no significant difference between the variances.

4. Comparative Study Based on Food Data

It is noted that the proposed test is a generalization of the existing test under neutrosophic statistics. It is also worth noting that the proposed test reduces to the existing test under classical statistics when no indeterminacy is found in the data. Therefore, the efficiency of the proposed test will be given in terms of the measure of indeterminacy, information, and flexibility. The neutrosophic form of $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$ is given as $\gamma_N F_N = 0.06 + 0.28 I_{\gamma_N F_N}; I_{\gamma_N F_N} \in [0, 0.7857]$. As discussed earlier, the first part 0.06 shows the value of statistic under classical statistics, the second part $0.28 I_{\gamma_N F_N}$ presents the indeterminate part, and $I_{\gamma_N F_N} \in [0, 0.7857]$ is the measure of uncertainty associated with the statistic $\gamma_N F_N \in [\gamma_L F_U, \gamma_L F_U]$. The proposed test statistic becomes the existing test statistic when $\gamma_L F_U = 0$. From the study, it can be noted that the proposed test statistic has $\gamma_N F_N \in [0.06, 0.28]$. It means, under an uncertain environment, the decision makers can expect the value of statistics from 0.06 to 0.28. On the other hand, the existing statistic gives only the determined value which is not adequate under an indeterminate environment. Therefore, the proposed test is more flexible than the existing test. In addition to this flexibility, the proposed test provides additional information about the measure of indeterminacy that is 0.7857. The proposed test gives information about three events associated with H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$. The probability of accepting H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ is 0.95, the probability of committing of a type-I error (the probability of rejecting H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ when it is true) is 0.05, and the chance of indeterminacy is 0.7857. From this comparison, it is clear that the proposed test gives more information, suitable, and flexible than the existing test. Therefore, the decision makers can apply the proposed test for testing H_0: $\sigma_{1N}^2 = \sigma_{2N}^2$ under indeterminacy.

5. Concluding Remarks

The present study introduced the neutrosophic statistical test to investigate the difference between variances of two populations when the correlation was exsiting in pair observations. The procedure and statistic of the proposed test under neutrosophic statistics were introduced in this paper. The proposed test is an extension of the existing F-test when correlation exists in pair observations. The application of the proposed test was given using the food industry data. The comparative study showed the efficiency of the proposed test over the existing test in terms of knowledge, flexibility, and adequacy. The proposed test using big data can be considered as future research. The proposed test using various sampling schemes can also be considered for future research.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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