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EVALUATING NUTRITIONAL EFFECTS IN TWO GROUPS OF PET DOGS USING AN UNEQUAL-VARIANCE *t*-TEST WITH IMPRECISE DATA

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Abstract

The existing *t*-test under classical statistics is used when all observations in the data are determinate. In case of uncertain and

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imprecise observations, the existing *t*-test cannot be applied. In this paper, a *t*-test for two populations when variances are unknown and unequal in practice will be introduced when the data has imprecise observations. The test statistic will be introduced for imprecise observations. The testing procedure of the proposed *t*-test will be discussed considering the degree of uncertainty. The applications of the proposed *t*-test will be discussed using pet dogs fed data. From the data analysis, the proposed *t*-test was found to be more informative than the existing *t*-test under classical statistics.

1. Introduction

Statistical tests have been applied in various fields for decision-making. Among them, student *t*-test is very common and popular to test the hypothesis about the mean of two populations, see Kebalepile and Chakane [1]. This test is applied to investigate whether two populations' means are equal or not. The *t*-test is applied when the sample size is less than 30 and variances of populations are equal/unequal and unknown. The test statistic when the variances of two populations are unknown but equal is different from the test statistic when the variances are unknown and unequal. The test is applied for testing the null hypothesis that two populations/groups have the same means vs. the alternative hypothesis that two populations/groups differ in means. Feng et al. [2] used the *t*-test for quality control data from the medical field. Mishra et al. [3] discussed various statistical tests and applied them to medical data. Kim [4] applied the *t*-test using clinical data. The mathematical expectation of the sample variance in sampling can be seen in Al Zaim and AlAita [5].

Statistical tests and methods have been widely used in analyzing the data obtained from animals. Neto and Ostrensky [6] analyzed the statistical methods used in veterinary science. Madouasse et al. [7] discussed the use of statistical analysis for animal epidemiology data. Palarea-Albaladejo and McKendrick [8] suggested the use of statistical design for the animal data. Gizzarelli et al. [9] worked on clinical findings of dogs' diets. Piper et al. [10] provided the guidelines for statistical analysis of animal trials. More information on the use of statistical methods for veterinary science can be seen in Lean et al. [11], Roberts et al. [12], Kazimierska et al. [13], Hoummady et al. [14] and Dodd et al. [15].

Smarandache [16] discussed that neutrosophic statistics can be effectively used for the analysis of imprecise or interval data. Smarandache [17] proved that neutrosophic statistics (NS) is more informative than classical and interval statistics. Chen et al. [18, 19] presented the methodology to analyze neutrosophic data. NS can be applied for the analysis of imprecise data and gives information about the measure of indeterminacy. More information on the use of NS can be seen in Alhabib and Salama [20], Polymenis [21], AlAita and Aslam [22], Aslam [23] and statistical analysis for missing data in the design of experiment can be seen in Khali et al. [24].

Aslam et al. [25] presented the *t*-test under NS when variances are equal but unknown. This existing *t*-test cannot be applied when the variances of two populations are unequal. By exploring the literature and best of our knowledge, there is no work on the *t*-test under NS for unequal variances of two populations. In this paper, we present the design of a *t*-test when variances are unknown and unequal, together with the modification of the *t*-test statistic under NS. Furthermore, the testing procedure is presented which is applied to the real data obtained from pet animal feed data. From the analysis, it is expected that the proposed test will be effective to be applied for imprecise data as compared to the existing *t*-test under classical statistics.

2. The Proposed *t*-test

In this section, we present the design of a *t*-test under NS for unknown and unequal variances.

2.1. Method-1

Suppose that $X_N \in [X_L, X_U]$ is a neutrosophic random variable of *n* that can be expressed in neutrosophic form as $X_N = X_L + X_U I_N$;

$I_N \in [I_L, I_U]$. Note that X_L, $X_U I_N$ and $I_N \in [I_L, I_U]$ are the lower, indeterminate and degree of indeterminacy, respectively. Note that the neutrosophic random variable $X_N \in [X_L, X_U]$ reduces to a random variable under classical statistics when $I_L = 0$. Based on the information, the neutrosophic mean for the first sample can be derived as follows:

$$\overline{X}_{1N} = \frac{\sum_{i=1}^{n_1}(X_L + X_U I_{1N})}{n_1} = \overline{X}_{1L} + \overline{X}_{1U} I_{1N};\ I_{1N} \in [I_{1L}, I_{1U}]. \quad (1)$$

The neutrosophic mean for the second sample can be derived as follows:

$$\overline{X}_{2N} = \frac{\sum_{i=1}^{n_2}(X_L + X_U I_{2N})}{n_2} = \overline{X}_{2L} + \overline{X}_{2U} I_{2N};\ I_{2N} \in [I_{2L}, I_{2U}], \quad (2)$$

where n_1 and n_2 denote the first sample size and second sample size, respectively. Also, $I_{iL}(i = 1, 2)$ denotes the level of indeterminacy in the first and second samples, respectively.

The neutrosophic sample variance for the first group is derived as follows:

$$S_{1N}^2 = \frac{\sum_{i=1}^{n_1}(X_{i1N} - \overline{X}_{1N})^2}{n_1 - 1} = S_{1N}^2 + S_{1N}^2 I_{1NS};\ I_{1NS} \in [I_{1LS}, I_{1US}]. \quad (3)$$

The neutrosophic sample variance for the second group is derived as follows:

$$S_{2N}^2 = \frac{\sum_{i=1}^{n_2}(X_{i2N} - \overline{X}_{2N})^2}{n_2 - 1} = S_{2N}^2 + S_{2N}^2 I_{2NS};\ I_{2NS} \in [I_{2LS}, I_{2US}]. \quad (4)$$

Also, $I_{iLS}(i = 1, 2)$ denotes the level of indeterminacy in the first and second sample variances, respectively.

The neutrosophic test statistic $t_N \in [t_L, t_U]$ for the proposed *t*-test for imprecise data is given by

$$t_N = \frac{(\overline{X}_{1N} - \overline{X}_{2N}) - (\mu_{1N} - \mu_{2N})}{\sqrt{\left(\frac{S_{1N}^2}{n_1} + \frac{S_{2N}^2}{n_2}\right)}} = t_L + t_U I_{t_N};\ I_{t_N} \in [I_{t_L}, I_{t_U}], \quad (5)$$

where I_{t_N} denotes the level of indeterminacy in the test statistic.

Note that the proposed test statistic is the generalization of the existing t-test under classical statistics. The first value of test statistic t_L denotes the classical statistics, $t_U I_{t_N}$ is the indeterminate part and $I_{t_N} \in [I_{t_L}, I_{t_U}]$ is the degree of uncertainty. The test statistic $t_N \in [t_L, t_U]$ reduces to statistic under classical statistics when $t_L = 0$. The neutrosophic degree of freedom (ndf) for the proposed t-test is given by

$$v_N = \left\{\frac{\left\{\frac{S_{1L}^2}{n_1} + \frac{S_{2L}^2}{n_2}\right\}}{\left\{\frac{S_{1L}^4}{n_1^2(n_1 - 1)} + \frac{S_{2L}^4}{n_2^2(n_2 - 1)}\right\}}\right\} + \left\{\frac{\left\{\frac{S_{1U}^2}{n_1} + \frac{S_{2U}^2}{n_2}\right\}}{\left\{\frac{S_{1U}^4}{n_1^2(n_1 - 1)} + \frac{S_{2U}^4}{n_2^2(n_2 - 1)}\right\}}\right\} I_{v_N};$$

$$I_{v_N} \in [I_{v_L}, I_{v_U}]. \quad (6)$$

2.2. Method-II

Chen et al. [18] discussed the way to analyze the neutrosophic data. They discussed the basic operations for neutrosophic random numbers. Following Chen et al. [18], the neutrosophic means for the first sample and second sample are given in equation (1) and equation (2). The sum of the squares of differences for the first sample can be calculated as

$$\sum_{i=1}^{n_1} (X_{1iN} - \overline{X}_{1N})^2$$

$$= \sum_{i=1}^{n_1} [(X_{1iL} - \overline{X}_{1L})^2, ((X_{1iL} - \overline{X}_{1L}) + 1 \times (X_{1iU} - \overline{X}_{1U}))^2]. \quad (7)$$

The sum of the squares of differences for the second sample can be calculated as

$$\sum_{i=1}^{n_2}(X_{2iN}-\overline{X}_{2N})^2$$

$$=\sum_{i=1}^{n_2}[(X_{2iL}-\overline{X}_{2L})^2,\ ((X_{2iL}-\overline{X}_{2L})+1\times(X_{2iU}-\overline{X}_{2U}))^2]. \tag{8}$$

The neutrosophic variance for the first sample is given by

$$S_{1N}^2=\frac{\sum_{i=1}^{n_1}[(X_{1iL}-\overline{X}_{1L})^2,\ ((X_{1iL}-\overline{X}_{1L})+1\times(X_{1iU}-\overline{X}_{1U}))^2]}{n_1-1}. \tag{9}$$

The neutrosophic variance for the second sample is given by

$$S_{1N}^2=\frac{\sum_{i=1}^{n_2}[(X_{2iL}-\overline{X}_{2L})^2,\ ((X_{2iL}-\overline{X}_{2L})+1\times(X_{2iU}-\overline{X}_{2U}))^2]}{n_2-1}. \tag{10}$$

The neutrosophic test statistic $t_N \in [t_L, t_U]$ for the proposed t-test for imprecise data is given by

$$t_N=\frac{(\overline{X}_{1N}-\overline{X}_{2N})-(\mu_{1N}-\mu_{2N})}{\sqrt{\left(\frac{S_{1N}^2}{n_1}+\frac{S_{2N}^2}{n_2}\right)}};\quad I_{t_N}\in[I_{t_L}, I_{t_U}]. \tag{11}$$

3. Application Using Dog Feed Data

The application of both methods with the help of real data will be given in this section.

Method-I. The application of method-1 will be given with the help of dog feed data. According to Parthiban and Gajivaradhan [26], "interval data are given the gain in weights (in lbs) of pet dogs fed on two kinds of diets A and B". The data is taken from Parthiban and Gajivaradhan [26] and reported in Table 1. Veterinary experts are interested to investigate the nutritional effect of two diets on pet dogs. They are interested to investigate either diet A and diet B has the same effect on increasing the weight of dogs. To apply the proposed test, it is assumed that variances are unknown and unequal. The veterinary experts are interested to investigate the null hypothesis H_0:

nutrition effect of two diets does not differ significantly vs. the alternative hypothesis H_1: nutrition effect of two diets differs significantly. To test this hypothesis, the necessary calculations of the proposed test for nutrition data are given by

The neutrosophic mean for diet A is given by

$$\overline{X}_{1N} = 21.75 + 24.42 I_{1N}; \quad I_{1N} \in [0, 0.1104].$$

The neutrosophic mean for diet B is given by

$$\overline{X}_{2N} = 19.80 + 23.47 I_{2N}; \quad I_{2N} \in [0, 0.1564],$$

where $n_1 = 12$ and $n_2 = 15$.

The neutrosophic sample variance for diet A is given by

$$S_{1N}^2 = 27.84 + 30.08 I_{1NS}; \quad I_{1NS} \in [0, 0.0573].$$

The neutrosophic sample variance for diet B is given by

$$S_{2N}^2 = 25.89 + (-25.26) I_{2NS}; \quad I_{2NS} \in [0, 0.0249].$$

The neutrosophic test statistic $t_N \in [t_L, t_U]$ nutrition data is given by

$$t_N = 0.9695 + (-0.4640) I_{t_N}; \quad I_{t_N} \in [0, 1.0894].$$

The ndf is given by

$$v_N = 32.89 + (-22.69) I_{v_N}; \quad I_{v_N} \in [0, 0.4495].$$

The tabulated value at $\alpha = 0.05$ is $[2.01, 2.07]$.

By comparing $t_N \in [0.9695, 0.4640]$ with tabulated values, the null hypothesis is that the nutrition effect of the two diets does not differ significantly.

Method-II. Now, the application of method-II will be given using the same data given in Table 1. To investigate the null hypothesis H_0: nutrition effect of two diets does not differ significantly vs. the alternative hypothesis

H_1: nutrition effect of two diets differs significantly. The necessary calculations are presented as:

The sum of the square of differences for the first sample can be calculated as

$$\sum_{i=1}^{n_1}(X_{1iN}-\overline{X}_{1N})^2 = [306.25,\ 1263.67].$$

The sum of the square of differences for the first sample can be calculated as

$$\sum_{i=1}^{n_2}(X_{2iN}-\overline{X}_{2N})^2 = [362.4,\ 1418.93].$$

The neutrosophic variance for the first sample is given by

$$S_{1N}^2 = [27.84,\ 114.88].$$

The neutrosophic variance for the second sample is given by

$$S_{1N}^2 = [25.88,\ 101.35].$$

The neutrosophic test statistic $t_N \in [t_L,\ t_U]$ for the proposed t-test for imprecise data is given by

$$t_N = 0.9695 + (-0.2351)I_{t_N}; \quad I_{t_N} \in [0,\ 3.1238].$$

The ndf is $[23.31,\ 23.00]$ and the tabulated value at $\alpha = 0.05$ is 2.069.

By comparing $t_N \in [0.9695,\ 0.2351]$ with tabulated values, the null hypothesis is that nutrition effect of the two diets does not differ significantly.

4. Comparative Studies

Now, we discuss the advantages and efficiency of the proposed t-test under classical statistics with the existing t-test under classical statistics and the t-test using interval statistics. As mentioned earlier, the proposed test is a generalization of the existing t-test using classical statistics and interval-statistics.

The proposed *t*-test is reduced to the existing *t*-test proposed by Kanji [27] when no imprecise observation is found in the data. From the pet dog's nutrition data, the neutrosophic test statistic from method-I and method-II are given by $t_N = 0.9695 - 0.4640 I_{t_N}$; $I_{t_N} \in [0, 1.0894]$ and $t_N = 0.9695 - 0.2351 I_{t_N}$; $I_{t_N} \in [0, 3.1238]$, respectively. The first value 0.9695 in both methods presents the value of the test statistic for the existing test mentioned in Kanji [27]. The second values $0.4640 I_{t_N}$ and $0.2351 I_{t_N}$ are indeterminate parts from method-I and method-II, respectively. From this information, it can be seen that the proposed *t*-test provides the values of test statistic from 0.9695 to 0.4640 and 0.9695 to 0.2351 with the degree of uncertainty of 1.0894 and 3.1238, respectively. It is important to note that when the degree of uncertainty is 1.0894 or 3.1238, we need decreasing trends in test statistic values. Parthiban and Gajivaradhan [26] presented the analysis using interval statistics. By comparing the results of the proposed test with those Parthiban and Gajivaradhan [26], it can be seen that the proposed test gives in information about the indeterminate parts that are associated with the degree of uncertainty. On the other hand, the *t*-test using interval statistics does not give information about the degree of indeterminacy and indeterminate parts. In nutshell, the use of neutrosophic transformation in the *t*-test makes it more efficient than those of classical statistics and interval statistics. From this analysis, it can be seen that the proposed test is more flexible and informative than classical statistics and interval statistics. In addition, the existing tests ignore information about degree of uncertainty/imprecision which is always associated with the imprecise data.

Table 1. The dog feed data

Diet-A	Diet-B	Diet-A	Diet-B
[18, 19]	[22, 26]	[20, 24]	[20, 24]
[16, 18]	[27, 31]	[27, 30]	[11, 15]
[30, 32]	[25, 28]	[18, 22]	[14, 17]
[28, 30]	[12, 16]	[21, 24]	[17, 21]
[22, 24]	[16, 20]		[25, 27]
[14, 16]	[18, 22]		[19, 22]
[28, 32]	[26, 30]		[23, 25]
[19, 22]	[22, 28]		

5. Concluding Remarks

Two methods to design *t*-test for unknown and unequal variances under neutrosophic statistics are presented in this paper. In practice, the measurement data is always imprecise. The existing *t*-tests under classical statistics and interval-statistics do not give information about the degree of imprecise. The proposed *t*-tests found to be effective and information than the existing tests. The proposed *t*-test gives information about the degree of uncertainty. From the study, it is concluded that in case of uncertainty or in the presence of imprecise data, the use of the proposed *t*-test will be recommended. The proposed *t*-test gives more information as compared to the existing tests. The proposed *t*-test can be used in medical science, political science and industry. The proposed test can be applied where imprecise data is recorded from the complex process.

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