Food Analytical Methods

Food Quality Inspection using Uncertain Rank Data

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Response Letter

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The author is deeply thankful to the editor and reviewers for their valuable suggestions to improve the quality of the paper.

Reviewer #1:

1) In section 2 pages 5 and 6, the author has used the hypothesis test as null hypothesis H0 and alternative hypothesis also H0. An author should recheck these Steps.

Response: These typos have been corrected in the revised paper.

2) The author should add more explanation in the conclusion section.

Response: The conclusion section has been expanded as suggested.

Reviewer #2:

The author uses the neutrosophic statistics in the food industry. It is good research and well organized.

Response: Thank you very much

In order for a better correlation with other papers, the author should add more references on the neutrosophic statistics in food industry
for example from this site http://fs.unm.edu/NS/NeutrosophicStatistics.htm

Response: Some references about neutrosophic statistics in the food industry have been added as suggested.

Food Quality Inspection using Uncertain Rank Data

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Abstract

The rank correlation test for agreement in multiple judgments under classical statistics cannot be applied when uncertainty/indeterminacy is present in rank data. In this paper, a rank correlation test for agreement in multiple judgments under neutrosophic statistics will be introduced. The proposed test has the capability to be applied when imprecise rank data is available. The proposed test is applied using the food quality data and compared with the existing tests. The analysis of food data is shown that the proposed test is productive and more explanatory than the existing tests.

Keywords: Statistical test; inference; classical statistics; simulation; food data

1 Introduction

The significance of the data or consistency in judgment cannot be checked without the help of statistical tests. Therefore, the statistical tests have been used in all areas of scientific research, see, for example, (Ali & Bhaskar, 2016) and (Greenland et al., 2016). The rank correlation test for agreement (RCTFA) in multiple judgments has been applied for testing the consistency of persons in a panel. This test is applied to test the null hypothesis whether the independent opinion of several judges in a panel is correlated or not. (Raghunathan & Quantity, 2003) presented the test for checking the homogeneity of correlation coefficients. (Kanji, 2006) presented RCTFA in multiple judgments with the application. (Kramer, Mileva, & Ritchie, 2018) presented the correlation analysis for faces data. More applications of statistical tests can be seen in (Regis, Postma, & van den Heuvel, 2017) and (Flores, Fernández-Casal, Naya, Tarrío-Saavedra, & Bossano, 2018).

The statistical tests under classical statistics are applied in decision-making when all the parameters or observations in the data are sure. But, in real life, the assumption of certainty about the parameters/data is not true always. (Viertl, 2006) pointed out that "statistical data are frequently not precise numbers but more or less non-precise also called fuzzy. Measurements of continuous variables are always fuzzy to a certain degree". When the data is imprecise, the statistical tests using fuzzy-logic can be used for the decision making. (Bodenhofer, Klawonn, & Computing, 2008) worked on robust rank correlation using the fuzzy approach. (Pandian & Kalpanapriya, 2014) used the fuzzy sets in designing the statistical test. (Osmani, Banik, Ali, & assessment, 2019) worked on a correlation test using fuzzy logic and applied it in water science. (Booth & Paillusson, 2021) discussed the important issues in implementing the fuzzy-based statistical tests.

(Smarandache, 1998) proved that neutrosophic logic is the generalization of fuzzy logic. The neutrosophic logic is found be to more efficient than fuzzy-logic and interval-based analysis, see, for example, (Das & Edalatpanah, 2020) and (G El Barbary & Abu Gdairi, 2021). By implementing the idea of neutrosophic logic, (Smarandache, 2014) familiarized neutrosophic statistics. Classical statistics becomes the special case of neutrosophic statistics when the data is certain. (Chen, Ye, & Du, 2017) and (Chen, Ye, Du, & Yong, 2017) worked on analyzing the neutrosophic numbers for rock engineers' problems. (Sherwani et al., 2021), (Aslam, 2021) and

(Albassam, Khan, & Aslam, 2021) worked on neutrosophic statistics with applications. The applications of neutrosophic statistical in the food industry can be seen in (Aslam, Balamurali, Periyasamypandian, & Al-Marshadi, 2019) and (Al-Marshadi & Aslam, 2021)

The existing RCTFA in multiple judgments works when uncertain information about the rank data is available. The existing test completely ignored the information about the uncertainty/indeterminacy in rank data while making the decision about the hypothesis. By exploring the literature and best of our knowledge, there is no work on neutrosophic rank correlation test for agreement (NRCTFA) in multiple judgments. The main aim of the proposed NRCTFA in multiple judgments is to test the consistency between judges in a panel. The application of the proposed test will be given using the food quality data. It is expected that the proposed NRCTFA in multiple judgments will be efficient than several existing RCTFA in multiple judgments tests.

2 Method

The existing rank correlation test for agreement (RCTFA) in multiple judgments under classical statistics did not evaluate the measure of uncertainty/indeterminacy that is always presented in sample size selection, deciding the level of significance, and in observations in the data obtained from the complex or uncertain environment. To overcome these issues and enhance the performance of RCTFA in multiple judgments under neutrosophic statistics will be developed in this section. The main objective of the proposed test is to test the significance of correlations using the rank data from more than two committee members under uncertainty. In other words, the proposed neutrosophic rank correlation test for agreement (NRCTFA) in multiple judgments can be applied for testing the consistency among several judges in the presence of neutrosophy. The methodology of the proposed NRCTFA in multiple judgments can be explained as follows: Let neutrosophic series of rank numbers are denoted by $n_N = n_L + n_U I_{n_N}; I_{n_N} \epsilon \left[I_{n_L}, I_{n_U}\right]$ assigned by committee participants' $k_N = k_L + k_U I_{k_N}; I_{k_N} \epsilon \left[I_{k_L}, I_{k_U}\right]$ subjects, where n_L, k_L are the determined parts of neutrosophic forms, $n_U I_{n_N}, k_U I_{k_N}$ are the indeterminate parts, and $I_{n_N} \epsilon \left[I_{n_L}, I_{n_U}\right]$, $I_{k_N} \epsilon \left[I_{k_L}, I_{k_U}\right]$ are the measures of indeterminacy/uncertainty associated with ranks. Suppose that $n_N \epsilon [n_L, n_U]$ committee members assigned rank numbers of $k_N \epsilon [k_L, k_U]$

subjects. The necessary computations of the proposed test using the idea of Neutrosophy are given as follows:

Compute the neutrosophic quantity $S_N \epsilon [S_L, S_U]$ as follows

$$S_N = S_L + S_U I_{S_N}; I_{S_N} \epsilon \left[I_{S_L}, I_{S_U}\right] \quad (1)$$

where $S_N \epsilon [S_L, S_U]$ is defined by

$$S_N = \frac{n_N k_N (k_N^2 - 1)}{[12,12]} \quad (2)$$

Suppose that $S_{DN} \epsilon [S_{DL}, S_{DU}]$ denotes the sum of the square of the difference between $k_N \epsilon [k_L, k_U]$ subjects mean rank and overall neutrosophic mean rank. Let

$$D_{1N} = D_{1L} + D_{1U} I_{D_{1N}}; I_{D_{1N}} \epsilon \left[I_{D_{1L}}, I_{D_{1U}}\right] \quad (3)$$

where $D_{1N} \epsilon [D_{1L}, D_{1U}]$ is defined by

$$D_{1N} = \frac{S_{DN}}{n_N}; S_{DN} \epsilon [S_{DL}, S_{DU}], n_N \epsilon [n_L, n_U] \quad (4)$$

The quantity $D_{2N} \epsilon [D_{2L}, D_{2U}]$ in neutrosophic form is expressed by

$$D_{2N} = D_{2L} + D_{2U} I_{D_{2N}}; I_{D_{2N}} \epsilon \left[I_{D_{2L}}, I_{D_{2U}}\right] \quad (5)$$

where

$$D_{2N} = S_N - D_{1N}; S_N \epsilon [S_L, S_U], D_{1N} \epsilon [D_{1L}, D_{1U}] \quad (6)$$

The quantity $S_{1N}^2 \epsilon [S_{1L}^2, S_{1U}^2]$ in neutrosophic form can be expressed by

$$S_{1N}^2 = S_{1L}^2 + S_{1U}^2 I_{S_{1N}^2}; I_{S_{1N}^2} \epsilon \left[I_{S_{1L}^2}, I_{S_{1U}^2}\right] \quad (7)$$

where

$$S_{1N}^2 = \frac{D_{1N}}{k_N - 1}; D_{1N} \epsilon [D_{1L}, D_{1U}], k_N \epsilon [k_L, k_U] \quad (8)$$

The quantity $S_{2N}^2 \epsilon [S_{2L}^2, S_{2U}^2]$ in neutrosophic form can be expressed by

$$S_{2N}^2 = S_{2L}^2 + S_{2U}^2 I_{S_{2N}^2}; I_{S_{2N}^2} \epsilon \left[I_{S_{2L}^2}, I_{S_{2U}^2}\right] \quad (9)$$

where

$$S_{2N}^2 = \frac{D_{2N}}{k_N(n_N-1)}; D_{2N}\epsilon[D_{2L}, D_{2U}], k_N\epsilon[k_L, k_U], n_N\epsilon[n_L, n_U] \tag{10}$$

The neutrosophic statistic of the proposed NRCTFA in multiple judgments is expressed by

$$F_N = \frac{S_{1L}^2}{S_{2L}^2} + \frac{S_{1U}^2}{S_{2U}^2} I_{F_N}; I_{F_N}\epsilon\left[I_{F_L}, I_{F_U}\right] \tag{11}$$

The proposed statistic follows the neutrosophic F-distribution with the degree of freedom$\left(k_N - 1, k_N(n_N - 1)\right)$. The proposed statistic $F_N\epsilon[F_L, F_U]$ is the extension of several tests. The proposed test reduces to RCTFA in multiple judgments under classical statistics when I_{F_L}=0. The proposed test is also an extension of RCTFA in multiple judgments under interval statistics as the existing test did not utilize the information about the measure of indeterminacy.

The proposed NRCTFA in multiple judgments can be implemented in the following steps.

Step-1: State the null hypothesis H_0: judges are consistent vs. the alternative hypothesis H_1: judges are not consistent.

Step-2: State the level of significance α and select the critical value from (Kanji, 2006).

Step-3: Compute the value of the test statistic and compare it with the critical value.

Step-4: Do not reject H_0: judges are consistent if computed values of $F_N\epsilon[F_L, F_U]$ are less than the critical value.

3 Application of the Proposed Test using Food Data

The application of the proposed NRCTFA in multiple judgments will be given with the aid of the food data. Suppose that a panel of three judges is selected to check the quality of food of fast-food chain restaurants by tasting assessment. From the three judges, one judge is an expert in food testers. For the quality check, 10 items of chicken the product are selected and judges are requested to rank the quality of the product on a special taste criterion. During ranking, suppose that the indeterminacy/uncertainty is found in assigning the rank is found. For simplicity, let the measure of intermediacy be 10%. Under uncertainty, the existing RCTFA in multiple judgments under classical statistics cannot be applied. The proposed NRCTFA in multiple judgments under neutrosophic statistics can be applied effectively. The null hypothesis for the assessment can be set as: are three judges consistent vs. the alternative hypothesis that three judges are not consistent. The rank data of the judges in the panel is shown in Table 1. The numerical calculation of the proposed test is shown in Table 2. The calculations of other quantities assuming 10% indeterminacy are calculated as follows. For example, the quantity $S_N \epsilon [S_L, S_U]$ is calculated as

$$S_N = 247.5(1 + 0.1); I_{S_N} \epsilon [0,0.10] = 272.25$$

The quantity $D_{1N} \epsilon [D_{1L}, D_{1U}]$ is calculated as

$$D_{1N} = 73(1 + 0.1); I_{D_{1N}} \epsilon [0,0.1] = 80.3$$

The quantity $D_{2N} \epsilon [D_{2L}, D_{2U}]$ is calculated as

$$D_{2N} = 174.5(1 + 0.1); I_{D_{2N}} \epsilon [0,0.1] = 191.95$$

The quantity $S_{1N}^2 \epsilon [S_{1L}^2, S_{1U}^2]$ in neutrosophic form can be expressed by

$$S_{1N}^2 = 8.11(1 + 0.1); I_{S_{1N}^2} \epsilon [0,0.1] = 8.92$$

The quantity $S_{2N}^2 \epsilon [S_{2L}^2, S_{2U}^2]$ in neutrosophic form can be expressed by

$$S_{2N}^2 = 9.59(1 + 0.1); I_{S_{2N}^2} \epsilon [0,0.1] = 10.55$$

The statistic of the proposed test is calculated as

$$F_N = 0.8451(1 + 0.8451); I_{F_N} \epsilon [0,0.1] = 0.9296$$

The proposed statistic follows the neutrosophic F-distribution with the degree of freedom (9,20).

The proposed NRCTFA in multiple judgments can be implemented in the following steps.

Step-1: State the null hypothesis H_0: judges are consistent vs. the alternative hypothesis H_1: judges are not consistent.

Step-2: State the level of significance $\alpha = 0.05$ and select the critical value 2.39 from (Kanji, 2006).

Step-3: The computed value of F_N is 0.9296

Step-4: Do not reject H_0: judges are consistent as computed values F_N is less than critical value 2.39.

Based on the analysis, it is concluded that three judges are consistent regarding the quality of the product of fast-food chain restaurants.

Table 1: The rank data by a panel

	Rank numbers									
	A	B	C	D	E	F	G	H	I	J
Judge 1	3	6	1	2	7	4	10	8	9	5
Judge 2	6	5	9	3	1	4	10	7	2	8
Judge 3	9	1	2	10	4	6	8	5	7	3

Table 2: The computations of the proposed test

	Rank numbers										
	A	B	C	D	E	F	G	H	I	J	Total
Judge 1	3	6	1	2	7	4	10	8	9	5	55
Judge 2	6	5	9	3	1	4	10	7	2	8	55
Judge 3	9	1	2	10	4	6	8	5	7	3	55
Total Score	18	12	12	15	12	14	28	20	18	16	165
Average	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	16.5	165
Difference	1.5	-4.5	-4.5	-1.5	-4.5	-2.5	11.5	3.5	1.5	-0.5	

4 Simulation Study using Food Data

To investigate the effect of the measure of the indeterminacy/uncertainty on the proposed statistic $F_N\epsilon[F_L, F_U]$, a simulation is performed in this section. The various values of I_{F_N} are selected and the values of $F_N\epsilon[F_L, F_U]$ are generated and placed in Table 3. From Table 3, it can be seen that the result of the proposed statistic is the same as the RCTFA in multiple judgments under classical statistics when $I_{F_N}\epsilon[0,0]$. It is worth noting that as the values of F_U increases as the values I_{F_U} increases from 0 to 1.0. From this trend, it can be clearly concluded that the measure of indeterminacy affects the values of test statistic $F_N \epsilon [F_L, F_U]$. The decision about the null hypothesis is also shown in the same table. Although, the decision about the null hypothesis is the same at all values of I_{F_U} but it affects the values of the test statistic significantly.

Table 3: Effect of indeterminacy on the proposed statistic

I_{F_N}	$F_N \epsilon [F_L, F_U]$	Decision about H_0	I_{F_N}	$F_N \epsilon [F_L, F_U]$	Decision about H_0
[0,0]	[0.8451,0.8451]	Do not reject H_0	[0,0.1]	[0.8451,0.9296]	Do not reject H_0
[0,0.01]	[0.8451,0.8536]	Do not reject H_0	[0,0.2]	[0.8451,1.0141]	Do not reject H_0
[0,0.02]	[0.8451,0.8620]	Do not reject H_0	[0,0.3]	[0.8451,1.0986]	Do not reject H_0
[0,0.03]	[0.8451,0.8705]	Do not reject H_0	[0,0.4]	[0.8451,1.1831]	Do not reject H_0
[0,0.04]	[0.8451,0.8789]	Do not reject H_0	[0,0.5]	[0.8451,1.2677]	Do not reject H_0
[0,0.05]	[0.8451,0.8874]	Do not reject H_0	[0,0.6]	[0.8451,1.3522]	Do not reject H_0
[0,0.06]	[0.8451,0.8958]	Do not reject H_0	[0,0.7]	[0.8451,1.4367]	Do not reject H_0
[0,0.07]	[0.8451,0.9043]	Do not reject H_0	[0,0.8]	[0.8451,1.5212]	Do not reject H_0
[0,0.08]	[0.8451,0.9127]	Do not reject H_0	[0,0.9]	[0.8451,1.6057]	Do not reject H_0
[0,0.09]	[0.8451,0.9212]	Do not reject H_0	[0,1]	[0.8451,1.6902]	Do not reject H_0

5 Comparative Studies using Food Data

As mentioned earlier, the proposed NRCTFA in multiple judgments is the generalization of several existing tests. The advantages of the proposed NRCTFA in multiple judgments under neutrosophic statistics will be compared with the existing RCTFA in multiple judgments under classical statistics, the RCTFA in multiple judgments using interval-statistics and RCTFA in multiple judgments under fuzzy logic. The neutrosophic form of the statistic using the food data is given as: $F_N = 0.8451 + 0.8451 I_{F_N}; I_{F_N} \epsilon [0,0.1]$. Note here that the first part 0.8451 denotes the value of RCTFA in multiple judgments under classical statistics. The second part $0.8451 I_{F_N}$ denotes the indeterminate part of the proposed test and $I_{F_N} \epsilon [0,0.1]$ is the measure of indeterminacy/uncertainty. The proposed NRCTFA in multiple judgments reduces to RCTFA in multiple judgments under classical statistics when $I_{F_L} = 0$. Therefore, the existing RCTFA in multiple judgments under classical statistics is a special case of the proposed test. By comparing the results of the proposed test with RCTFA in multiple judgments under classical statistics, it can be seen that the existing RCTFA in multiple judgments under classical statistics gives only the information about the determined part. On the other hand, the proposed test gives information about the undetermined part and measure of indeterminacy/uncertainty associated with the test. From the comparison, it is clear that the proposed test is efficient than RCTFA in multiple judgments under classical statistics.

The interval-statistics uses the data in intervals for the analysis while the classical statistics is applied when the data is crisp. The beauty of interval-statistics is that it uses the data in intervals to capture or approximate the data within intervals. The RCTFA in multiple judgments under interval-statistics gives the values of statistic in an interval only. For example, from the food data, the value of test statistic using interval-statistics will be from 0.8451 to 0.9296. Again, the existing RCTFA in multiple judgments under interval-statistics is unable to evaluate the measure of indeterminacy/uncertainty. Therefore, by comparing the proposed test with RCTFA in multiple judgments under interval-statistics, it is concluded that the proposed test efficient than RCTFA in multiple judgments under interval-statistics.

The applications of RCTFA in multiple judgments under fuzzy logic are limited. The test designed using fuzzy logic only uses interval analysis. The proposed NRCTFA in multiple judgments uses set analysis theory that is the generalization of interval-analysis. Therefore, the proposed test can be applied to any type of set. The proposed test states that the probability of accepting (a measure of truth) the null hypothesis is 0.95, the probability of committing an error is 0.05 (a measure of falseness) and the measure of indeterminacy associated with the test is 0.10. The proposed test gives the information about the three measures while the NRCTFA in multiple judgments using fuzzy-logic gives the information about the measure of truth and measure of falseness. Therefore, the proposed test is more informative than NRCTFA in multiple judgments using fuzzy-logic. From the comparative studies, it is concluded that the proposed test is effective, informative and flexible than the existing tests.

5.1 Power of the Test

In this subsection, the efficiency of the proposed RCTFA in multiple judgments will be completed with RCTFA in multiple judgments under classical statistics in terms of the power of the test, say $(1-\beta)$, where β is the chance of accepting the null hypothesis when it is not true. The values of $(1-\beta)$ are presented for various values of α and shown in Table 4. The values of the power of the test are plotted and shown in Figure 1. From Table 4 and Figure 1, it is clear that the values of the power of the test for the proposed test are higher than the values of the power of the test of the existing test at all values of α. For example, when α=0.05, the proposed test gives the values of the power of the test from 0.9508 to 0.9519 while the existing test provides the value of the power of the test 0.949. From Figure 1, it is clear that the power curve of the existing test is lower than the power curves of the proposed test. Therefore, the proposed test is efficient than the existing test in terms of the power of the test.

Table 4: The power of two tests

α	Existing Test	Proposed Test
	$(1-\beta)$	$(1-\beta)$
0.01	0.988	[0.99,0.992]
0.02	0.9788	[0.98,0.978]
0.04	0.9551	[0.9609,0.9613]
0.05	0.949	[0.9508,0.9519]
0.06	0.934	[0.936,0.942]
0.08	0.9173	[0.9209,0.9221]
0.1	0.904	[0.91,0.914]

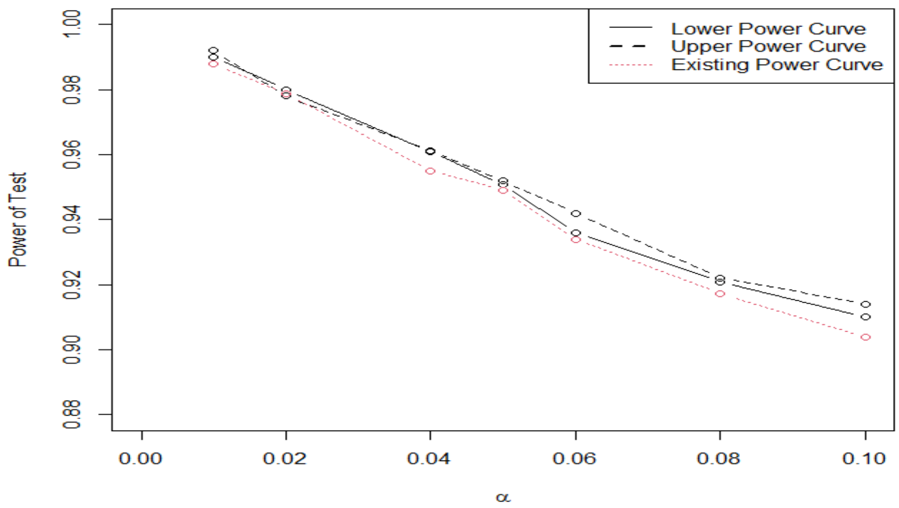

Figure 1: Power curves of two tests

6 Concluding Remarks

In this paper, a rank correlation test for agreement in multiple judgments under neutrosophic statistics was introduced. The modification of the test statistic under neutrosophic was given. The proposed test statistic was the generalization of several tests. The application of the proposed test on food data showed that the proposed test is effective than the other existing tests. The existing test did not utilize the measure of indeterminacy/uncertainty. The proposed test was found to be flexible, informative, and adequate to be applied under an indeterminate environment. The proposed test can be applied in sport, political science, and food quality where the data is obtained from the personal Judgements. More statistical properties for the proposed test can be studied in future research. Introducing the computer software/program for the proposed test is another area of future research. The proposed test using double sampling can be designed as future research.

Data Availability: The data is given in the paper.

Conflict of Interest: No conflict of interest regarding the paper.

Ethical Approval: This article does not contain any studies with human participants performed by any of the authors.

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Informed consent: Not applicable

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