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GUIDE FOR SENSORY EVALUATION OF FOODS

PART 3 STATISTICAL ANALYSIS OF DATA

Section 2 Ranking and Scoring Tests

(First Revision)

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GUIDE FOR SENSORY EVALUATION OF FOODS

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Section 2 Ranking and Scoring Tests

(First Revision)

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Indian Standard

GUIDE FOR SENSORY EVALUATION OF FOODS

PART 3 STATISTICAL ANALYSIS OF DATA

Section 2 Ranking and Scoring Tests

(First Revision)

0. FOREWORD

0.1 This Indian Standard (Part 3/Sec 2) (First Revision) was adopted by the Indian Standards Institution on 15 July 1983, after the draft finalized by the Sampling Methods for Food Products and Agricultural Inputs Sectional Committee had been approved by the Agricultural and Food Products Division Council.

0.2 Sensory evaluation of foods is assuming increasing significance as this provides information which may be utilized for quality control, assessment of process variation, cost reduction, product improvement, new product development and market analysis.

0.3 The sensory evaluation of foods depends on proper panel selection; environmental conditions and equipment for the test; selection of representative sample, its preparation and presentation; terminology; methods employed; and statistical techniques applied for the analysis of data. In order to facilitate easy application and provide guidelines on the above aspects, this standard had been published in three parts. Whereas this part of the standard covers the statistical analysis of data, Part 1 covers the optimum requirements and Part 2 the methods and evaluation cards.

0.4 This standard (Part 3) was originally issued in 1975. While revising this standard, the Committee decided to split it into two sections, Section 1 dealing with difference/preference tests and Section 2 with ranking and scoring tests. This standard is being revised so as to bring together various tests of the same type having same field of application. The various statistical tests are presented in a more simplified form so that a common user may be able to understand them easily.

0.5 In this revised version (Sec 2), the technique of analysis of variance (ANOVA) has been deleted as the validity of this technique for analysing the data pertaining to sensory evaluation experiments is a matter of controversy. However, Friedman's test for concordance and range test, included in this standard, can be used as alternatives to ANOVA. In order to study the significance of difference in two independent means, *t*-test and Mann-Whitney *U*-test along with the necessary conditions for the validity of *t*-test have been included. Paired *t*-test and Wilcoxon Mann-Whitney test are included for pairwise comparison of samples. To enable the user of this standard to test the overall significance among the samples when each panelist tests only a subset of samples, Durbin's test has been included.

0.6 The descriptions given in this standard are designed to suit the sensory evaluation personnel and more detailed procedures of some of the statistical tests are included in IS : 6200 (Part 1)-1977* and IS : 6200 (Part 2)-1977†.

0.7 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960‡.

1. SCOPE

1.1 This standard (Part 3/Sec 2) covers ranking and scoring tests. The various tests included in this standard are Kramer's rank-sum test, Wilcoxon Mann-Whitney test, Friedman's test for concordance, Durbin's test, *t*-test, Mann-Whitney *U*-test, Wilcoxon matched-pairs signed-ranks test and range test.

2. TERMINOLOGY

2.0 For the purpose of this standard, the definitions given in IS : 5126 (Part 1)-1969§ and the following, shall apply.

2.1 Arithmetic Mean — Sum of the values of the observations divided by the number of observations.

2.2 Critical Difference — The magnitude of difference which will be significant at a chosen level of significance, calculated from the value of of the standard error of the difference.

2.3 Critical Region — The region of possible values of the statistic used such that if the value of the statistic which results from the observed values belongs to the region, the null hypothesis will be rejected.

*Statistical tests of significance : Part 1 *t*-, Normal and *F*-tests (*first revision*).

†Statistical tests of significance, : Part 2 χ^2 test (*first revision*).

‡Rules for rounding off numerical values (*revised*).

§Glossary of general terms for sensory evaluation of foods: Part 1 Methodology.

2.4 Degrees of Freedom — The number of independent component values which are used to determine a statistic.

2.5 Error—The difference between observed value and its true or expected value. It is not synonymous with mistake.

2.6 Hypothesis, Alternate — The hypothesis of the difference or non-equivalence between effects of the method(s). The alternate hypothesis may be two-sided or one-sided.

2.7 Hypothesis, Null — The hypothesis of the equivalence or no difference between the effects of the method(s) so that the sample emanates from the same population.

2.8 Level of Significance — The probability (or risk) of rejecting the null hypothesis when it is true.

2.9 Parameter — A quantity which partly or wholly specifies the distribution of a characteristic of the population.

2.10 Non-parametric Tests — Tests which do not require the assumptions regarding the distribution of the variable in the population from which the sample was drawn.

2.11 Parametric Tests — Tests based on certain specific assumptions regarding the distribution of the variable in the population from which the sample was drawn.

2.12 Population — The totality of items under consideration.

2.13 Probability — If a trial results in n possible outcomes which are equally likely such that any one of them can occur at a time and out of which m cases are favourable to the happening of an event E, the probability of event E is given by $P(E) = \frac{m}{n}$.

2.14 Probability Distribution — The distribution which determines the probability that a random variable takes any given value or belongs to a given set of values. The probability over the whole interval of variation of the variable equals one.

2.15 Random Variable — A variable which may take any of the values of a specified set of values and to which is associated a probability distribution.

2.16 Range — The difference between the largest and the smallest observed values of a measurable characteristic.

2.17 Replication — The execution of experiment more than once essentially under the same experimental conditions.

2.18 Statistical Errors

2.18.1 *Error of the First Kind* — Error in concluding that there is a difference when in fact there is no difference, resulting in rejection of the null hypothesis when it is true.

2.18.2 *Error of the Second Kind* — Error in concluding that there is no difference when in fact there is difference, accepting the null hypothesis when it is false.

2.19 Test, One-sided — A test in which the statistic used in unidimensional and the critical region is the set of values lower (or greater) than a given number. In the case of directional difference tests where the direction of difference is known or assumed in advance, a one-sided test has to be used.

2.20 Test, Two-sided — A test in which a statistic used is unidimensional and in which a set of values lower than a first given number and the set of values greater than a second given number form the critical region.

2.21 Variance — The quotient obtained by dividing the sum of squares of observations from their mean by one less than the number of observations in the sample.

2.22 Standard Deviation — It is the positive square root of variance.

2.23 Standard Error (SE) — Standard deviation of an estimator, the standard error provides an estimate of the random part of the error involved in estimating a population parameter from a sample.

2.24 Statistic — A function of observed values derived from the sample.

3. SYMBOLS

3.1 Following symbols have been used for expression of sensory evaluation results:

N = Number of items in the population

n = Number of samples/sample pairs

m = Number of panelists

k = Number of preference into which sample is classified

Σ = Summation

$| \; |$ = Absolute value

x_i = Measurement on ith item

$$\bar{x} = \text{Mean} = \frac{x_1 + x_2 + \dots\dots\dots + x_m}{m}$$

s = Standard deviation = $\sqrt{\dfrac{(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots\ldots + (x_m - \bar{x})^2}{m - 1}}$

R = Range = The difference between the largest and the smallest of x_1's

s' = Pooled standard deviation = $\sqrt{\dfrac{\Sigma(x - \bar{x})^2 + \Sigma(y - \bar{y})^2}{m_1 + m_2 - 2}}$; m_1 and m_2 being the number of panelists testing the two samples.

4. GENERAL CONSIDERATIONS

4.1 In addition to statistical considerations mentioned with respective methods of analysis, psychological errors which may be committed by a panelist have also to be kept in view. These errors may be commited due to his previous knowledge of the test sample or method of presentation of test samples, tendency to repeat previous impressions, reluctance to use extreme values on a scale specially for unfamiliar foods, tendency to rate the adjacent quality factors similar as in the case of simultaneous scoring of colour texture, odour, taste and general acceptability on the same set of samples, and tendency to continue to give the same response when a series of slowly increasing or decreasing stimuli is presented.

4.2 The number of panelists for these tests shall be seven. However, depending upon the purpose of the experiment and type of panel, this number shall be sufficiently large. For general guidance regarding the number of panelists, IS : 6273 (Part 2)-1971* may be referred.

4.3 In the presentation of test samples, the following precautions shall be taken:

a) Provision shall be made for sufficient quantity of bulk sample which can be divided into the necessary number of individual samples;

b) The panelists shall not be able to draw the conclusions as to the nature of samples from the way in which they are presented. The various pairs of the series shall be prepared in an identical fashion (same apparatus, same vessel and same quantities of products);

c) The temperature of the samples in any given pair shall be the same and, if possible, the same as that of all other samples in a given test series; and

d) The vessels containing the test samples shall be suitably coded, and coding shall be different for each test.

*Guide for sensory evaluation of foods: Part 2 Methods and evaluation cards.

5. RANKING TESTS

5.1 Ranking is the natural extension of paired comparison for more than two samples. It is rapid and facilitates the testing of several samples at a time. If there are *n* samples, it is required to assign them the ranks 1, 2, 3, ..., *n* with ' 1 ' representing the sample ranked highest in intensity/quality and *n* the lowest. The first step in the analysis of ranking data is to determine whether the differences among samples are significant, if so, the next step is to cluster them into homogeneous groups.

5.1.1 *Kramer's Rank-Sum Test*

5.1.1.1 The aim of this test is to study whether rank-sums (or equivalently mean ranks) for various samples differ significantly and which of the samples is significantly superior or inferior to others in preference ranking. It is applicable only when each panelist examines all the samples.

5.1.1.2 The rank-sum for each sample is computed first. Table 1A and Table 1B (*see* pages 23 and 24) give the critical values of rank-sums at 5 percent and 1 percent level of significance respectively. Each cell in these tables has two pairs of values. The upper pair of critical values gives the smallest and largest rank-sums such that the probability of any of the observed rank-sums being exceeded by the smaller value and exceeding the largest value is less than or equal to the specified level of significance. If any of the observed rank-sums is outside the range of upper pair of values, the samples may be considered to be significantly different. The comparison with lower pair of values will reveal as to which of the samples is significantly superior or inferior to others in preference ranking.

5.1.1.3 Table 1A and Table 1B include 12 samples and 20 panelists. If the number of samples or panelists is more, the rank-sums can be analysed by χ^2-test for concordance as applied to rank order data (*see* **5.1.3**).

5.1.1.4 *Example 1* — Four samples of a beverage were given to each of 20 panelists for preference ranking. The ranks 1, 2, 3, 4 were assigned to the most preferred, the next preferred and so on in a selected quality attribute. It is required to determine with 99 percent probability whether the differences among samples are significant. The preference rankings are given below:

Panelists	*Samples*			
	I	II	III	IV
1	1	3	4	2
2	2	4	3	1
3	3	1	2	4

Panelists	*Samples* I	II	III	IV
4	1	3	2	4
5	1	3	2	4
6	1	3	2	4
7	2	4	1	3
8	1	4	2	3
9	1	2	3	4
10	1	3	2	4
11	1	3	4	2
12	1	3	4	2
13	1	3	2	4
14	1	2	4	3
15	1	3	2	4
16	1	2	4	3
17	1	3	2	4
18	1	2	3	4
19	1	3	2	4
20	1	3	4	2
Total	24	57	54	65

The critical value for 4 samples and 20 panelists at 1 percent level of significance is $\begin{smallmatrix}36 - 64\\38 - 62\end{smallmatrix}$ (*see* Table 1B). As two of the rank-sums (24 and 65) are outside the range of upper pair of critical values, it may be concluded that the differences among samples are highly significant. The comparison of rank-sums with the lower pair of critical values reveals that sample I is significantly superior and sample IV is significantly inferior to others in preference ranking at 1 percent level of significance.

5.1.2 *Wilcoxon Mann-Whitney Test* — This test is used for pairwise comparison of various samples.

5.1.2.1 For each panelist in a sample, count ' 1 ' for the number of ranks in the other sample which are higher; count ½ for equal and zero for lower. The sum of these counts for a pair of samples is called the *C*-statistic. The greater of the two, C or $m^2 - C$, where m is the number of panelists is a *U*-statistic used in this test.

5.1.2.2 *U* values for different sample pairs are arranged in the form of a matrix. For example, if there are four samples I, II, III and IV the matrix obtained shall be given as below:

Samples	*I*	*II*	*III*	*IV*
I	—			
II		—		
III			—	
IV				—

5.1.2.3 The critical value (*U'*) of *U* is obtained as:

$$U' = \frac{m^2}{2} + mQ\sqrt{\frac{2m+1}{24}}$$

Where *m* is the number of panelists and *Q* is the critical value obtained from Table 2 (*see* page 25) corresponding to a given number of samples at desired level of significance.

5.1.2.4 The critical value (*U'*) so obtained is rounded off to the nearest integer. All the *U* values greater than the critical value *U'* are marked with an asterisk (*) in the matrix. The groups of samples containing at least one significant (*) value among them are considered heterogeneous. Thus different homogeneous groups of samples can be identified.

5.1.2.5 *Example 2* — If the ranks for each of the four different samples given in **5.1.1.4** are arranged in ascending order, the following data are obtained:

Samples			
I	II	III	IV
1	1	1	1
1	2	2	2
1	2	2	2
1	2	2	2
1	2	2	2
1	3	2	3
1	3	2	3
1	3	2	3
1	3	2	3
1	3	2	4
1	3	2	4

	Samples			
	I	II	III	IV
	1	3	3	4
	1	3	3	4
	1	3	3	4
	1	3	4	4
	1	3	4	4
	1	3	4	4
	2	4	4	4
	2	4	4	4
	3	4	4	4
Total	24	57	54	65

It is intended to identify the homogeneous groups of samples that can be made.

The *C*-statistic for samples I and II according to **5.1.2.1** is computed as below:

$$C(\text{ I, II }) = (19\tfrac{1}{2} + 19\tfrac{1}{2} + \ldots\ldots \text{ 17 times}) + (15 + \tfrac{1}{2} \times 4) + (15 + \tfrac{1}{2} \times 4) + (3 + \tfrac{1}{2} \times 12)$$

$$= 374{\cdot}5$$

$$m^2 - C = 400 - 374{\cdot}5 = 25{\cdot}5$$

In this case $U = 374{\cdot}5$, as the value of $m^2 - C$ is smaller than C.

Similarly U values for other sample pairs namely, (I, III); (II, III); (II, IV) and (III, IV) can be obtained. These values, arranged in the form of a matrix, are given below:

Samples	*I*	*II*	*III*	*IV*
I	—			
II	374·5*	—		
III	367.0*	225·5	—	
IV	378·4*	260·0	261·5	—

The value of Q obtained from Table 2 corresponding to 4 samples at 5 percent level of significance is 3·63. The critical value (U') is obtained as follows:

$$U' = \frac{20^2}{2} + 20 \times 3{\cdot}63 \sqrt{\frac{2 \times 20 + 1}{24}} = 294{\cdot}89$$

$$= 295 \text{ (rounded off to nearest integer)}$$

5.1.2.6 All the U values greater than 295 in the matrix given above are marked with an asterisk (*). As groups of samples containing at least one significant U value among them are considered heterogeneous, (I) and (II, III, IV) form two different groups. Thus the data can be represented as (I), (II, III, IV) meaning thereby that sample I is significantly different from II, III and IV samples whereas among II, III and IV there is no significant difference.

5.1.3 *Friedman's Test for Concordance* — When different panelists evaluate the same samples or when the same panelist evaluates a set of samples, testing of concordance among the rankings can be done by using the χ^2 statistic.

5.1.3.1 In order to test the significance of difference in n related samples with respect to mean ranks, the Friedman's statistic T is used to determine whether rank-sums (or equivalently mean ranks) differ significantly. The statistic T which is distributed as χ^2 with ($n - 1$) degrees of freedom is defined as:

$$T = \frac{12}{mn (n + 1)} \sum_{i=1}^{n} R_i^2 - 3m (n + 1)$$

where

m = number of panelists,

n = number of samples, and

R_i = sum of ranks for ith sample.

5.1.3.2 The value of T is computed and is compared with the critical value given in Table 3 (*see* page 26) for ($n - 1$) degrees of freedom at a chosen level of significance. If the computed value of T is greater than or equal to the critical value, the null hypothesis that there is no significant difference in the samples with respect to rank-sums is rejected at that level of significance.

5.1.3.3 *Example 3* — Three similar market samples of apples A, B and C are given to 18 penelists for preference ranking 1, 2 and 3 to the most preferred, the next best and the next, respectively. It is required to be examined whether the differences in three types of apples are significant. The rankings given by the panelists are given below:

Panelists	*Market Samples*		
	A	B	C
1	1	3	2
2	2	3	1
3	1	3	2
4	1	2	3
5	3	1	2
6	2	3	1
7	3	2	1
8	1	3	2
9	3	1	2
10	3	1	2
11	2	3	1
12	2	3	1
13	3	2	1
14	2	3	1
15	3	2	1
16	3	2	1
17	3	2	1
18	2	3	1
Total	40	42	26

The null hypothesis is that there is no significant difference in the samples A, B and C with respect to rank-sums.

Here $m = 18$, $n = 3$, $R_1 = 40$, $R_2 = 42$ and $R_3 = 26$

$$\text{Hence } T = \frac{12}{18 \times 3 \times 4} [40^2 + 42^2 + 26^2] - 3 \times 18 \times 4 = 8{\cdot}40$$

with 2 (= 3 − 1) degrees of freedom.

Referring to Table 3, the critical value of χ^2 for 2 degrees of freedom at 5 percent level of significance is 5·99 and hence the null hypothesis is rejected at 5 percent level meaning thereby that the differences in three types of apples are found to be significant at that level.

5.1.4 *Durbin's Test*

5.1.4.1 When each panelist tests only a subset of samples which are ranked by him according to some criterion of interest, the overall significance of differences among samples may be tested by using the Durbin's T statistic defined as below:

$$T = \frac{12 (n - 1)}{rn (k - 1) (k + 1)} \sum_{j=1}^{n} R_j^2 - \frac{3r (n - 1) (k + 1)}{k - 1}$$

where

n = total number of samples to be tested,
r = number of times each sample is tested,
$r < m$, m being the number of panelists,
k = number of samples tested by each panelist, and
R_j = sum of ranks of the r values observed under jth sample.

5.1.4.2 As T follows a χ^2-distribution, the null hypothesis that there is no overall difference among samples is not rejected if the T value is less than the corresponding critical value of χ^2 obtained from Table 3 for ($n - 1$) degrees of freedom at desired level of significance.

5.1.4.3 *Example* 4 — Shelf-life studies on 6 orange juice samples specifically with reference to changes in the intensity of aroma, were conducted using a ranking procedure. 20 panelists participated in the evaluation to complete a full replication, each one testing 3 samples only. The number of replicates for each sample were 10. It is required to determine whether overall differences among samples are significant. The data obtained is tabulated as follows:

Panelists	*Ranks for Samples*					
	1	2	3	4	5	6
	Ranks					
1	1	3	2	—	—	—
2	—	—	—	1	2	3
3	1	2	—	3	—	—
4	—	—	1	—	2	3
5	1	2	—	—	3	—
6	—	—	1	2	—	3
7	1	3	—	—	—	2
8	—	—	1	2	3	—
9	1	—	3	2	—	—
10	—	1	—	—	3	2
11	2	—	1	—	3	—
12	—	1	—	2	—	3
13	1	—	2·5	—	—	2·5
14	—	1	—	3	2	—
15	1	—	—	2·5	2·5	—
16	—	3	2	—	—	1
17	3	—	—	2	—	1
18	1	—	—	—	2	3
19	—	1	2	—	3	—
20	—	1	3	2	—	—
R_j	13	18	18·5	21·5	25·5	23·5

The null hypothesis is that there are no significant overall differences among samples.

Here

n = total number of samples = 6,
k = number of samples compared at one time = 3,
m = number of penalists = 20,
r = number of times each sample is tested = 10, and

$$T = \frac{12 \times 5}{10 \times 6 \times 2 \times 4} [13^2 + 18^2 + 18{\cdot}5^2 + 21{\cdot}5^2 + 25{\cdot}5^2 + 23{\cdot}5^2]$$

$$- \frac{3 \times 10 \times 5 \times 4}{2} = 12{\cdot}50.$$

The critical value of χ^2 according to Table 3 for 5 (= 6 − 1) degrees of freedom at 5 percent level of significance is 11·07. As the computed value of T is greater than the critical value of χ^2, the null hypothesis of no significant overall differences may be rejected at 5 percent level.

6. SCORING TESTS

6.1 Whenever samples from two or more food products are rated by numerical scoring methods by a group of panelists, scoring tests are used to analyse the resulting data.

6.2 In sensory analysis of foods, responses of the panelists are usually given in classificatory, ranking or hedonic scale and the data is analysed by non-parametric tests. The parametric tests are made use of only if the assumptions of the relevant test are satisfied and a continuous scale can be built based on quality changes or differences in quality that can occur in the product and a panel is trained to use the scale as a continuous scale. Such elaborate procedures for building up the methodology for sensory analysis are necessary where all the samples are not available together for either ordering or categorising. For example, if apples are to be tested for their quality changes under different methods of storage and under different conditions, they are expected to become ripe and be evaluated at different times. In this situation the necessity to score them individually for the purpose of comparison arises. Thus if the scale is continuous, directly related to the quality changes and as many points on the scale as can be seen to be very clearly different are marked and described, the parametric tests are used provided the other assumptions of the relevant test are also satisfied.

6.3 *t*-Test for Two Independent Means — If samples for two food products are evaluated by a group of panelists by numerical scoring methods, the significance of difference in mean scores can be tested by the

Student's *t*-test. It is a parametric test which is used only if the following assumptions are satisfied:

a) Samples are drawn at random from normal populations with the same variance (unknown); and

b) The measurements can be considered to be in a continuous scale as explained in **6.2**.

6.3.1 If two samples of size m_1 and m_2 are taken for two products and are rated by m_1 and m_2 panelists respectively, the t statistic is defined as:

$$t = \frac{\bar{x} - \bar{y}}{s' \sqrt{\frac{1}{m_1} + \frac{1}{m_2}}}$$

where $\bar{x}$ and $\bar{y}$ are sample means and s' refers to the standard deviation of the pooled samples and is given by:

$$s' = \sqrt{\frac{\Sigma(x - \bar{x})^2 + \Sigma(y - \bar{y})^2}{m_1 + m_2 - 2}}$$

The t in this case has ($m_1 + m_2 - 2$) degrees of freedom and its critical value is given in Table 4 (*see* page 27) for the chosen level of significance. If the computed value of t is greater than or equal to the critical value, the null hypothesis of no significant difference in the two means is rejected at that level.

6.3.1.1 *Example 5* — In a study on the effect of cold storage prior to ripening of Cavendish banana, one group of 10 panelists rated a market sample and another group of 8 panelists (representing the same normal population) rated the experimental sample on a 9-point scale. It is required to test whether there is significant difference between the market and experimental samples. The scores given by different panelists are given below:

Market Sample (x)	*Experimental Sample* (y)
6	7
8	7
6	8
8	7
8	7
9	6
6	7
8	9
6	
8	

The null hypothesis is that there is no significant difference in the market and experimental samples against an alternate hypothesis that they are significantly different (two-sided).

For market samples, the mean $\bar{x} = 7{\cdot}30$ and the sample size $m_1 = 10$, whereas for the experimental sample, the mean $\bar{y} = 7{\cdot}25$ and the sample size $m_2 = 8$. The pooled standard deviation (s') for the two samples is $= 1{\cdot}05$.

Here the t statistic is calculated as

$$t = \frac{\bar{x} - \bar{y}}{s' \sqrt{\frac{1}{m_1} + \frac{1}{m_2}}} = \frac{7{\cdot}30 - 7{\cdot}25}{1{\cdot}05 \sqrt{\frac{1}{10} + \frac{1}{8}}} = 0{\cdot}100$$

The critical value of t (two-sided) with 16 ($= 10 + 8 - 2$) degrees of freedom obtained from Table 4 is 2·120 at 5 percent level of significance. Since the calculated value of t is smaller than the critical value, the null hypothesis regarding the equality of market and experimental samples, is not rejected.

6.4 Mann-Whitney *U*-Test

6.4.1 It is a non-parametric test used to test whether two independent samples have been drawn from the same population. It is the most useful alternative to the parametric t-test given in **6.3**. If the necessary conditions for the validity of t-test, as given in **6.3**, are not met, this test may be used.

6.4.2 In this test, two samples of size m_1 and m_2 such that $m_1 < m_2$ are taken from the two populations A and B, and are rated by m_1 and m_2 panelists respectively. The null hypothesis is that both the populations are same.

6.4.2.1 The observations from both the samples are combined and arranged in ascending order with the identity of samples preserved. The ranks are given in order of increasing size. The value of U is given by the number of times that an observation in the sample of size m_2 precedes an observation in the sample of size m_1. Similarly another value of U is obtained by counting the number of times that an observation in the sample of size m_1 precedes an observation in the sample of size m_2. In this way two values of U are obtained. The smaller of the two values is taken as value of U for testing the null hypothesis.

6.4.3 *Small Samples* — The following method shall be employed when m_2, the number of observations in the larger of two independent samples, is less than or equal to 20.

6.4.3.1 Combine all the observations of the two samples.

6.4.3.2 Rank the observations in increasing order of the combined samples that is, rank of 1 is given to the lowest observation in the combined samples, rank of 2 to the next lowest observation and so on.

6.4.3.3 Obtain the value of U by the method given in **6.4.2.1**. However for fairly large values of m_1 and m_2 this method of calculating U is difficult. Alternatively the following procedure may be adopted.

Denote by A if an observation belongs to the sample of size m_1 and B if it belongs to a sample of size m_2. Calculate the sum of ranks assigned to the sample with m_1 observations (say R_1). Similarly, find the sum of ranks assigned to the sample with m_2 observations (say R_2). In case a tie occurs, each of the tied observations are given the average of the ranks which they would have had if the values had differed slightly. Calculate the two values of U say, U_1 and U_2 by the following relation:

$$U_1 = m_1 m_2 + \frac{m_1 (m_1+1)}{2} - R_1$$

and $$U_2 = m_1 m_2 + \frac{m_2 (m_2+1)}{2} - R_2$$

where R_1 = sum of the ranks assigned to the sample with m_1 observations, and

R_2 = sum of the ranks assigned to the sample with m_2 observations.

6.4.3.4 Alternatively, one of the values U_1 (or U_2) may be calculated by the above formula and the other value U_2 (or U_1) may be obtained with the help of the following relation:

$$U_1 = m_1 m_2 - U_2$$

6.4.3.5 The smaller of the values U_1 and U_2 is chosen as the value of U.

6.4.3.6 This calculated value of U is compared with the critical value for a given m_1, m_2 and desired level of significance. The critical values for this purpose are given in Table 5 and Table 6 (for one-sided test) and Table 7 and Table 8 (for two-sided test) (*see* page 28 to 31). The null hypothesis is not rejected if the calculated value of U is greater than the critical value.

6.4.4 *Example 6* — For the data given in Example 5 the number of panelists rating market sample may be denoted by m_2 and the experimental sample by m_1. The sequence of observations of the two samples combined when arranged in ascending order is given by.

	B	*B*	*B*	*B*	*A*	*A*	*A*	*A*	*A*	*A*
Ranks	3·0	3·0	3·0	3·0	3·0	8·0	8·0	8·0	8·0	8·0
	B	*B*	*B*	*B*	*B*	*A*	*B*	*A*		
	13·5	13·5	13·5	13·5	13·5	13·5	17·5	17·5		

Where A denotes an observation from experimental sample and B denotes an observation from market sample.

Here R_1 = sum of ranks of observations from experimental sample = 74

R_2 = sum of ranks of observations from market sample = 97

$$U_1 = 80 + \frac{8 \times 9}{2} - 74$$

$$= 116 - 74 = 42$$

$$U_2 = 80 + \frac{10 \times 11}{2} - 97$$

$$= 135 - 97 = 38$$

Therefore U = Minimum of U_1 and $U_2 = 38$

6.4.4.1 The critical value (two-sided test) for $m_1 = 8$, $m_2 = 10$ and 5 percent level of significance is 17 (*see* Table 7). Since the calculated value of U is more than the critical value, the null hypothesis that there is no significant difference in the market and experimental samples is not rejected. It may be noted that the same conclusion was drawn by applying the t-test.

6.4.5 *Large Samples (m_2 larger than 20)* — As m_1 and m_2 increase in size, the distribution of U approaches normal with:

$$\text{Mean} = \frac{m_1 m_2}{2}$$

$$\text{and Variance} = \frac{m_1 m_2 (m_1 + m_2 + 1)}{12}$$

$$\text{Therefore } Z = \frac{\left| U - \frac{m_1 m_2}{2} \right|}{\sqrt{\frac{m_1 m_2 (m_1 + m_2 + 1)}{12}}}$$

in standardized normal variate. The value of Z is calculated and compared with the critical value of 1·96 (corresponding to 5 percent level of significance) or 2·58 (corresponding to 1 percent level of significance) for a two-sided test. For one-sided test, the calculated value is compared with the critical value of 1·645 (corresponding to 5 percent level of significance) or 2·325 (corresponding to 1 percent level of significance). The null hypothesis is not rejected if the calculated value is less than the critical value.

6.4.5.1 *Example 7* — In a study on the effect of particle size of wheat flour on the texture of *roti*, a panel of 25 panelists evaluated the texture of two *rotis* *A* and *B* prepared with wheat flours of different particle sizes, on a 9-point quantitative descriptive score card. It is required to examine whether the particle size of wheat flour has any significant effect on the texture of *rotis*. The scores are given below:

Panelist	*Roti*	
	A	*B*
1	4	6
2	5	7
3	4	4
4	5	6
5	6	4
6	4	7
7	6	7
8	6	8
9	6	8
10	7	6
11	6	6
12	7	7
13	5	6
14	4	4
15	4	6
16	6	6
17	5	6
18	6	8
19	4	6
20	5	5
21	8	6
22	7	6
23	6	6
24	5	5
25	5	5

Here the null hypothesis is that there is no significant difference in the texture of *rotis* *A* and *B* against an alternate hypothesis that they are different.

If the observations of the two samples are combined and arranged in ascending order, the following sum of ranks are obtained:

R_1 = sum of ranks of observations for *roti* *A* = 545

R_2 = sum of ranks of observations for *roti* $B = 730$

also $m_1 = m_2 = 25$

$$U_1 = 625 + \frac{25 \times 26}{2} - 545$$

$$= 625 + 325 - 545 = 405$$

$$U_2 = m_1 m_2 - U_1$$

$$= 625 - 405 = 220$$

Therefore U = Minimum (U_1, U_2) = 220

$$\text{Mean} = \frac{m_1 m_2}{2} = 312{\cdot}5$$

$$\text{Standard deviation} = \sqrt{\frac{m_1 m_2 (m_1 + m_2 + 1)}{12}} = \sqrt{\frac{625 \times 51}{12}} = 51{\cdot}5$$

$$Z = \frac{| 220 - 312{\cdot}5 |}{51{\cdot}5} = 1{\cdot}80$$

Since the calculated value of Z is less than 1·96, the null hypothesis is not rejected at 5 percent level of significance, thereby implying that particle size of wheat flour used for preparing a *roti* does not have significant effect on the texture of *rotis.*

6.5 *t*-Test for Paired Comparisons — When the same group of panelists evaluates a pair of samples of two grades of the same product, the observations of one sample correspond to the observations of the other. Thus the observations may occur in pairs, each pair arising under the same experimental conditions with the conditions varying from pair to pair. In such a case if the assumptions given in **6.3** are satisfied, *t*-test can be applied on the differences (d) between the observations in each pair to test whether the mean of the differences is significantly different from zero. The statistic t is computed as:

$$t = \frac{| \bar{d} - 0 |}{\sqrt{\frac{s^2_d}{m}}} \text{ with (m}-1\text{) degrees of freedom}$$

where $\bar{d} = \frac{\Sigma d}{m}$, $s^2_d = \frac{1}{m-1} \left[\Sigma d^2 - \frac{(\Sigma d)^2}{m} \right]$, and

m is the number of panelists.

The null hypothesis that the mean of the differences is not significantly different from zero is tested by comparing the computed value of t with the corresponding tabulated value given in Table 4.

6.5.1 *Example 8* — Eight trained panelists scored two pepper samples A and B for aroma intensity by adopting a 7-point numerical scoring scale.

It is required to examine whether there is significant difference in respect of aroma intensity between the two samples, sample *B* being known to be one with more intense aroma. The scores are given below:

Panelists	*Pepper A*	*Pepper B*	*Difference* $d(=A-B)$	d^2
1	2	4	— 2	4
2	5	6	— 1	1
3	3	5	— 2	4
4	3	5	— 2	4
5	4	6	— 2	4
6	5	6	— 1	1
7	5	5	0	0
8	4	5	— 1	1

$$\text{Here } \bar{d} = \frac{\Sigma d}{m} = \frac{-11}{8} = -1{\cdot}375$$

$$s^2_d = \frac{1}{8-1}\left[19 - \frac{11^2}{8}\right] = 0{\cdot}554$$

$$\text{and } t = \frac{|-1{\cdot}38|}{\sqrt{\frac{0{\cdot}55}{8}}} = 5{\cdot}228$$

The *t* test in this case is one-sided as the pepper *B* is known to have more intense aroma than *A*. The critical value of *t* (one-sided) with 7 degrees of freedom at 5 percent level of significance given in Table 4 is 1·895. As the computed value of *t* is greater than the critical value it may be concluded that pepper *B* has significantly more aroma than that of *A* at 5 percent level.

6.6 Wilcoxon Matched-Pairs Signed-Ranks Test

6.6.1 This is a non-parametric test based on the relative magnitude as well as the direction of the differences. Thus it gives more weight to a pair which shows a large difference than to a pair which shows a small difference.

6.6.2 For any matched pair, the difference between the two observations '*d*' is calculated. Such *d*'s are ranked without regard to sign, that is, a rank of 1 is given to the smallest *d* the rank of 2 to the next smallest and so on. Thus a difference of '− 1' will have a lower rank than a difference of either '+ 2' or '— 2'. Then the sign of the difference is assigned to each rank, that is, it is indicated as to which of the ranks are arising from the negative *d*'s and which ranks are from positive *d*'s.

TABLE 1A CRITICAL VALUES OF RANK SUMS AT 5% LEVEL OF SIGNIFICANCE

(*Clause* 5.1.1.2)

PANELISTS	SAMPLES RANKED										
	2	3	4	5	6	7	8	9	10	11	12
2	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	3-9	3-11	3-13	4-14	4-16	4-18	5-19	5-21
3	—	—	—	4-14	4-17	4-20	4-23	5-25	5-28	5-31	5-34
	—	4-8	4-11	5-13	6-15	6-18	7-20	8-22	8-25	9-27	10-29
4	—	3-11	5-15	6-18	6-22	7-25	7-29	8-32	8-36	8-39	9-43
	—	5-11	6-14	7-17	8-20	8-23	10-26	11-29	13-31	14-34	15-37
5	—	6-14	7-18	8-22	9-26	9-31	10-35	11-39	12-43	12-48	13-52
	6-9	7-13	8-17	10-20	11-24	13-27	14-31	15-35	17-38	18-42	20-45
6	7-11	8-16	9-21	10-26	11-31	12-36	13-41	14-46	15-51	17-55	18-60
	7-11	9-15	11-19	12-24	14-28	16-32	18-36	20-40	21-45	23-49	25-53
7	8-13	10-18	11-24	12-30	14-35	15-41	17-46	18-52	19-58	21-63	22-69
	8-13	10-18	13-22	15-27	17-32	19-37	22-41	24-46	26-51	28-56	30-61
8	9-15	11-21	13-27	15-33	17-39	18-46	20-32	22-58	24-64	25-71	22-77
	10-14	12-20	15-25	17-31	20-36	23-41	25-47	28-52	31-57	33-63	36-68
9	11-16	13-23	15-30	17-37	19-44	22-50	24-57	26-64	28-71	30-78	32-85
	11-16	14-22	17-28	20-34	23-44	26-46	29-52	32-58	35-64	38-70	41-76
10	12-18	15-25	17-33	20-40	22-48	25-55	27-63	30-70	32-78	35-85	37-93
	12-18	16-24	19-31	23-37	26-44	30-50	34-56	37-63	40-70	44-76	47-83
11	13-20	16 28	19-36	22-44	25-52	28-60	31-68	34-76	36-85	39-93	42-101
	14-19	18-26	21-34	25-41	29-48	33-55	37-62	41-69	45-76	49-83	53-90
12	15-21	18-30	21-39	25-47	28.56	31-65	34-74	38-82	41-91	44-100	47-109
	15-21	19-29	24-36	25-44	32-52	37-59	41-67	45-75	50-82	54-90	58- 98
13	16-23	20-32	24-41	27-51	31-60	35-69	38-79	42-88	45-98	49-107	52-117
	17-22	21-31	26-39	31-47	35-56	40-64	45-72	50-80	54-89	59-97	64-105
14	17-25	22-34	26-44	30-54	34-64	38-74	42-84	46-94	50-104	50-114	57-125
	18-24	23-35	26-42	33-51	38-60	44-68	43-77	54-86	59-95	65-103	70-112
15	19-26	23-37	28-47	32-58	37-68	41-79	46-89	50-100	54-111	58-122	63-132
	19-26	25-35	30-45	36-54	42-63	47-73	53-82	59-91	64-101	70-110	75-120
16	20-28	25-39	30-50	35-61	40-72	45-83	49-95	54-106	59-117	63-129	68-140
	21-27	27-37	33-47	39-57	45-67	51-77	57-87	62-98	69-107	75-117	81-127
17	22-29	27-41	32-53	38-64	43-76	48-88	53-100	58-112	63-124	68-136	73-148
	22-29	28-40	35-50	41-61	48-71	54-82	61-92	67-103	74-113	81-123	87-134
18	23-31	29-43	34-56	40-78	46-80	52-92	57-105	61-118	68-130	73-143	79-155
	24-30	30-42	37-53	44-64	51-75	58-86	65-97	72-108	79-119	86-130	93-141
19	24-33	30-46	37-58	43-71	49-84	55-97	61-110	67-123	73-136	78-150	84-163
	25-32	32-44	39-56	47-67	54-79	62-90	69-102	76-114	84-125	91-137	99-148
20	26-34	32-48	39-61	45-95	52-88	58-102	65-118	71-129	77-143	83-157	90-170
	26-34	34-46	42-58	50-70	57-83	65-95	73-107	81-119	89-131	97-143	106-155

TABLE 1B CRITICAL VALUE OF RANK TOTALS AT THE 1% LEVEL OF SIGNIFICANCE

(*Clause* 5.1.1.2)

Panelists	Samples Ranked										
	2	3	4	5	6	7	8	9	10	11	12
2	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	3-19	3-21	3-23
3	—	—	—	—	—	—	—	—	4-29	4-32	4-35
	—	—	—	4-14	4-17	4-20	5-22	5-25	6-27	6-30	6-33
4	—	—	—	5-19	5-23	5-27	6-30	6-34	6-38	6-42	7-45
	—	—	5-15	6-18	6-22	7-25	8-28	8-32	9-35	10-38	10-42
5	—	—	6-19	7-23	7-28	8-32	8-37	9-41	9-46	10-50	10-55
	—	6-14	7-18	8-22	9-26	10-30	11-34	12-38	13-42	14-46	15-50
6	—	7-17	8-22	9-27	9-33	10-30	11-43	12-48	13-53	13-59	14-64
	—	8-16	9-21	10-26	12-30	13-35	14-40	16-44	17-49	18-54	20-58
7	—	8-20	10-25	11-31	12-37	13-43	14-49	15-55	16-61	17-67	18-73
	8-13	9-19	11-24	12-30	14-35	16-40	18-45	19-51	21-56	23-61	25-66
8	9-15	10-22	11-29	13-35	14-42	16-48	17-55	19-61	20-68	21-75	23-81
	9-15	11-21	13-27	15-33	17-39	19-45	21-51	23-75	25-63	28-68	30-74
9	10-17	12-24	13-32	15-39	17-46	19-53	21-60	22-68	24-75	26-82	27-90
	10-17	12-24	15-30	17-37	20-43	22-50	25-56	27-63	30-69	32-76	35-82
10	11-19	13-27	15-35	18-42	20-50	22-58	24-66	26-74	28-82	30-90	32-98
	11-19	14-26	17-33	20-40	23-47	25-55	28-62	31-69	34-76	37-83	40-90
11	12-21	15-29	17-38	20-46	22-55	25-63	27-82	30-80	38-89	34-98	36-106
	13-20	16-28	19-36	22-44	25-52	29-59	32-67	35-75	39-82	42-90	45-98
12	14-22	17-31	19-41	22-50	25-59	28-68	31-77	33-87	36-96	39-105	42-114
	14-22	18-30	21-39	25-47	28-56	32-64	36-72	39-81	43-89	47-97	50-106
13	15-24	18-34	21-44	25-53	28-63	31-73	34-83	37-93	40-103	43-113	46-123
	15-24	19-34	23-42	27-51	31-60	35-69	39-78	44-86	48-95	52-104	56-113
14	16-26	20-36	24-46	27-57	31-67	34-78	38-88	41-98	45-109	48-120	51-131
	17-25	21-35	25-45	30-54	34-64	39-73	43-83	48-92	52-102	57-121	61-121
15	18-27	22-38	26-49	30-60	34-71	37-83	41-94	45-105	49-116	53-127	56-133
	18-27	23-37	28-47	32-58	37-68	42-78	47-88	52-98	57-108	62-118	67-128
16	19-29	23-41	28-52	30-64	38-76	41-87	45-99	49-111	53-123	57-135	62-146
	19-29	25-39	30-50	35-61	40-72	46-82	51-93	56-104	61-115	67-125	72-136
17	20-31	25-43	30-55	35-67	39-80	44-92	49-104	53-117	58-129	62-142	67-154
	21-30	26-42	32-53	38-64	43-76	49-87	55-98	60-110	66-121	72-132	78-143
18	22-32	27-45	32-58	37-71	42-84	47-97	52-110	57-123	32-136	67-149	72-162
	22-32	28-44	34-56	40-68	46-80	52-92	57-105	62-118	68-130	73-143	79-155
19	23-34	29-47	34-61	40-74	45-88	50-102	56-115	61-129	67-142	72-156	77-170
	24-33	30-46	36-59	43-71	49-84	56-96	62-109	89-121	76-133	82-146	89-158
20	24-36	30-50	36-64	42-78	48-92	54-106	60-120	65-135	71-149	77-163	82-178
	25-33	32-48	38-62	45-75	52-88	59-101	66-114	73-127	80-140	87-153	94-166

TABLE 2 UPPER PERCENTAGE POINTS (Q) OF THE DISTRIBUTION OF RANGE

(*Clause* 5.1.2.3)

SAMPLES	SIGNIFICANCE LEVEL		
	0·05	0·01	0·001
2	2·77	3·64	4·65
3	3·32	4·12	5·06
4	3·63	4·40	5·31
5	3·86	4·60	5·48
6	4·03	4·76	5·62
7	4·17	4·88	5·73
8	4·29	4·99	5·82
9	4·39	5·08	5·90
10	4·47	5·16	5·97
11	4·55	5·23	6·04
12	4·62	5·29	6·09
13	4·68	5·35	6·14
14	4·74	5·40	6·19
15	4·80	5·45	6·23
16	4·84	5·49	6·27
17	4·89	5·54	6·31
18	4·93	5·57	6·35
19	4·97	5·61	6·38
20	5·01	5·65	6·41

TABLE 3 CRITICAL VALUES OF χ^2-DISTRIBUTION

(*Clauses* 5.1.3.2 *and* 5.1.4.2)

Degrees of Freedom	Significance Level		
	0·05	0·01	0·001
1	3·84	6·64	10·83
2	5·99	9·21	13·82
3	7·82	11·34	16·27
4	9·49	13·28	18·46
5	11·07	15·09	20·52
6	12·59	16·81	22·46
7	14·07	18·48	23·32
8	15·51	20·09	26·12
9	16·92	21·67	27·88
10	18·31	23·21	29·59
11	19·68	24·73	31·26
12	21·03	26·22	32·91
13	22·36	27·69	34·53
14	23·69	29·14	36·12
15	25·00	30·58	37·70
16	26·30	32·00	39·25
17	27·59	33·41	40·79
18	28·87	34·81	42·31
19	30·14	36·19	43·82
20	31·41	37·57	45·32
21	32·67	38·93	46·80
22	33·92	40·29	48·27
23	35·17	41·64	49·73
24	36·42	42·98	51·18
25	37·65	44·31	52·62
26	38·89	45·64	54·05
27	40·11	46·96	55·48
28	41·34	48·28	56·89
29	42·56	49·59	58·30
30	43·77	50·89	59·70

TABLE 4 CRITICAL VALUES OF t-DISTRIBUTION

(*Clause* 6.3.1)

Degrees of Freedom	Significance Levels for: One-Sided Test			Two-Sided Test		
	0·05	0·01	0·001	0·05	0·01	0·001
1	6·314	31·821	318·31	12·706	63·657	636·62
2	2·920	6·965	22·326	4·303	9·925	31·598
3	2·353	4·541	10·213	3·182	5·841	12·924
4	2·132	3·747	7·173	2·776	4·604	8·610
5	2·015	3·365	5·893	2·571	4·032	6·869
6	1·943	3·143	5·208	2·447	3·707	5·959
7	1·895	2·998	4·785	2·365	3·499	5·408
8	1·860	2·896	4·501	2·306	3·355	5·041
9	1·833	2·821	4·297	2·262	3·250	4·781
10	1·812	2·764	4·144	2·228	3·169	4·587
11	1·796	2·718	4·025	2·201	3·106	4·437
12	1·782	2·681	3·930	2·179	3·055	4·318
13	1·771	2·650	3·852	2·160	3·012	4·221
14	1·761	2·624	3·787	2·145	2·977	4·140
15	1·753	2·602	3·733	2·131	2·947	4·073
16	1·746	2·583	3·686	2·120	2·921	4·015
17	1·740	2·567	3·646	2·110	2·898	3·965
18	1·734	2·552	3·610	2·101	2·878	3·922
19	1·729	2·539	3·579	2·093	2·861	3·883
20	1·725	2·528	3·552	2·086	2·845	3·850
21	1·721	2·518	3·527	2·080	2·831	3·819
22	1·717	2·508	3·505	2·074	2·819	3·792
23	1·714	2·500	3·485	2·069	2·807	3·767
24	1·711	2·492	3·467	2·064	2·797	3·745
25	1·708	2·485	3·450	2·060	2·787	3·725
26	1·706	2·479	3·435	2·056	2·779	3·707
27	1·703	2·473	3·421	2·052	2·771	3·690
28	1·701	2·467	3·408	2·048	2·763	3·674
29	1·699	2·462	3·396	2.045	2·756	3·659
30	1·697	2·457	3·385	2·042	2·750	3·646
∞	1·645	2·326	3·090	1·960	2·576	3·291

TABLE 5 CRITICAL VALUES OF *U* IN MANN-WHITNEY *U*-TEST (ONE-SIDED) FOR 5 PERCENT LEVEL OF SIGNIFICANCE

(*Clause* 6.4.3.6)

m_1 \ m_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	0
2	—	—	—	—	0	0	0	1	1	1	1	2	2	2	3	3	3	4	4	4
3	—	—	0	0	1	2	2	3	3	4	5	5	6	7	7	8	9	9	10	11
4	—	—	0	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18
5	—	0	1	2	4	5	6	8	9	11	12	13	15	16	18	19	20	22	23	25
6	—	0	2	3	5	7	8	10	12	14	16	17	19	21	23	25	26	28	30	32
7	—	0	2	4	6	8	11	13	15	17	19	21	24	26	28	30	33	35	37	39
8	—	1	3	5	8	10	13	15	18	20	23	26	28	31	33	36	39	41	44	47
9	—	1	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54
10	—	1	4	7	11	14	17	20	24	27	31	34	37	41	44	48	51	55	58	62
11	—	1	5	8	12	16	19	23	27	31	34	38	42	46	50	54	57	61	65	69
12	—	2	5	9	13	17	21	26	30	34	38	42	47	51	55	60	64	68	72	77
13	—	2	6	10	15	19	24	28	33	37	42	47	51	56	61	65	70	75	80	84
14	—	2	7	11	16	21	26	31	36	41	46	51	56	61	66	71	77	82	87	92
15	—	3	7	12	18	23	28	33	39	44	50	55	61	66	72	77	83	88	94	100
16	—	3	8	14	19	25	30	36	42	48	54	60	65	71	77	83	89	95	101	107
17	—	3	9	15	20	26	33	39	45	51	57	64	70	77	83	89	96	102	109	115
18	—	4	9	16	22	28	35	41	48	55	61	68	75	82	88	95	102	109	116	123
19	0	4	10	17	23	30	37	44	51	58	65	72	80	87	94	101	109	116	123	130
20	0	4	11	18	25	32	39	47	54	62	69	77	84	92	100	107	115	123	130	138

TABLE 6 CRITICAL VALUES OF *U* IN MANN-WHITNEY *U*-TEST (ONE-SIDED) FOR 1 PERCENT LEVEL OF SIGNIFICANCE

(*Clause* 6.4.3.6)

m_1 \ m_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—	—	0	0	0	0	0	0	1	1
3	—	—	—	—	—	—	0	0	1	1	1	2	2	2	3	3	4	4	4	5
4	—	—	—	—	0	1	1	2	3	3	4	5	5	6	7	7	8	9	9	10
5	—	—	—	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
6	—	—	—	1	2	3	4	6	7	8	9	11	12	13	15	16	18	19	20	22
7	—	—	0	1	3	4	6	7	9	11	12	14	16	17	19	21	23	24	26	28
8	—	—	0	2	4	6	7	9	11	13	15	17	20	22	24	26	28	30	32	34
9	—	—	1	3	5	7	9	11	14	16	18	21	23	26	28	31	33	36	38	40
10	—	—	1	3	6	8	11	13	16	19	22	24	27	30	33	36	38	41	44	47
11	—	—	1	4	7	9	12	15	18	22	25	28	31	34	37	41	44	47	50	53
12	—	—	2	5	8	11	14	17	21	24	28	31	35	38	42	46	49	53	56	60
13	—	0	2	5	9	12	16	20	23	27	31	35	39	43	47	51	55	59	63	67
14	—	0	2	6	10	13	17	22	26	30	34	38	43	47	51	56	60	65	69	73
15	—	0	3	7	11	15	19	24	28	33	37	42	47	51	56	61	66	70	75	80
16	—	0	3	7	12	16	21	26	31	36	41	46	51	56	61	66	71	76	82	87
17	—	0	4	8	13	18	23	28	33	38	44	49	55	60	66	71	77	82	88	93
18	—	0	4	9	14	19	24	30	36	41	47	53	59	65	70	76	82	88	94	100
19	—	1	4	9	15	20	26	32	38	44	50	56	63	69	75	82	88	94	101	107
20	—	1	5	10	16	22	28	34	40	47	53	60	67	73	80	87	93	100	107	114

TABLE 7 CRITICAL VALUES OF *U* IN MANN-WHITNEY *U*-TEST (TWO-SIDED) FOR 5 PERCENT LEVEL OF SIGNIFICANCE

(*Clause* 6.4.3.6)

m_1 \ m_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	0	0	0	0	1	1	1	1	1	2	2	2	2
3	—	—	—	—	0	1	1	2	2	3	3	4	4	5	5	6	5	7	7	8
4	—	—	—	—	1	2	3	4	4	5	6	7	8	9	10	11	11	12	13	13
5	—	—	—	1	2	3	5	6	7	8	9	11	12	13	14	15	17	18	19	20
6	—	—	1	2	3	5	6	8	10	11	13	14	16	17	19	21	22	24	25	27
7	—	—	1	3	5	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
8	—	0	2	4	6	8	10	13	15	17	19	22	24	26	29	31	34	36	38	41
9	—	0	2	4	7	10	12	15	17	20	23	26	28	31	34	37	39	42	45	48
10	—	0	3	5	8	11	14	17	20	23	26	29	33	36	39	42	45	48	52	55
11	—	0	3	6	9	13	16	19	23	26	30	33	37	40	44	47	51	55	58	62
12	—	1	4	7	11	14	18	22	26	29	33	37	41	45	49	53	57	61	65	69
13	—	1	4	8	12	16	20	24	28	33	37	41	45	50	54	59	63	67	72	76
14	—	1	5	9	13	17	22	26	31	36	40	45	50	55	59	64	67	74	78	83
15	—	1	5	10	14	19	24	29	34	39	44	49	54	59	64	70	75	80	85	90
16	—	1	6	11	15	21	26	31	37	42	47	53	59	64	70	75	81	86	92	98
17	—	2	6	11	17	22	28	34	39	45	51	57	63	67	75	81	87	93	99	105
18	—	2	7	12	18	24	30	36	42	48	55	61	67	74	80	86	93	99	106	112
19	—	2	7	13	19	25	32	38	45	52	58	65	72	78	85	92	99	106	113	119
20	—	2	8	13	20	27	34	41	48	55	62	69	76	83	90	98	105	112	119	127

TABLE 8 CRITICAL VALUES OF *U* IN MANN-WHITNEY *U*-TEST (TWO-SIDED) FOR 1 PERCENT LEVEL OF SIGNIFICANCE

(*Clause* 6.4.3.6)

m_1 \ m_2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	0
3	—	—	—	—	—	—	—	—	0	0	0	1	1	1	2	2	2	2	3	3
4	—	—	—	—	—	0	0	1	1	2	2	3	3	4	5	5	6	6	7	8
5	—	—	—	—	0	1	1	2	3	4	5	6	7	7	8	9	10	11	12	13
6	—	—	—	0	1	2	3	4	5	6	7	9	10	11	12	13	15	16	17	18
7	—	—	—	0	1	3	4	6	7	9	10	12	13	15	16	18	19	21	22	24
8	—	—	—	1	2	4	6	7	9	11	13	15	17	18	20	22	24	26	28	30
9	—	—	0	1	3	5	7	9	11	13	16	18	20	22	24	27	29	31	33	36
10	—	—	0	2	4	6	9	11	13	16	18	21	24	26	29	31	34	37	39	42
11	—	—	0	2	5	7	10	13	16	18	21	24	27	30	33	36	39	42	45	48
12	—	—	1	3	6	9	12	15	18	21	24	27	31	34	37	41	44	47	51	54
13	—	—	1	3	7	10	13	17	20	24	27	31	34	38	42	45	49	53	57	60
14	—	—	1	4	7	11	15	18	22	26	30	34	38	42	46	50	54	58	63	67
15	—	—	2	5	8	12	16	20	24	29	33	37	42	46	51	55	60	64	69	73
16	—	—	2	5	9	13	18	22	27	31	36	41	45	50	55	60	65	70	74	79
17	—	—	2	6	10	15	19	24	29	34	39	44	49	54	60	65	70	75	81	86
18	—	—	2	6	11	16	21	26	31	37	42	47	53	58	64	70	75	81	87	92
19	—	0	3	7	12	17	22	28	33	39	45	51	57	63	69	74	81	87	93	99
20	—	0	3	8	13	18	24	30	36	42	48	54	60	67	73	79	86	92	99	105

6.6.3 If the difference between any pair is zero, then that pair is dropped from the analysis and the sample size (m) is thereby reduced. It may also be possible that a tie may occur, that is, two or more pairs may have same numerical value of difference. The rank assigned in such cases is the average of the ranks which would have to be assigned if the '*d*'s' had differed slightly. For example, three pairs may have the value of '*d*' as − 1, − 1 and + 1. In this case each pair would be assigned the rank of 2, because the average of the ranks is $= \frac{1 + 2 + 3}{3} = 2$. Then the next '*d*' in order would receive the rank of 4, because the rank 1, 2, 3 have already been used.

6.6.4 Under the null hypothesis it is expected that the sum of the ranks having a plus sign and the minus sign should be equal. Therefore, if the sum of ranks of positive sign is very much different from that of negative sign, it is expected that there is a significant difference and the null hypothesis is rejected.

6.6.5 *Small Samples* — This method shall be employed when the number of panelists (m) is less than or equal to 25. Let T be the smaller sum of like signed ranks, that is, T is either the sum of the positive ranks or the sum of the negative ranks, whichever is smaller. The value of T is calculated from a sample of m pairs and compared with the critical value of T for a given sample size (m) and desired level of significance given in Table 9. Depending on the alternate hypothesis, a two-sided or one-sided, the appropriate critical value may be chosen from Table 9. If the critical value is less than the calculated value of T, the null hypothesis is not rejected.

6.6.5.1 *Example 9* — Ten trained panelists scored two ginger samples by adopting a 8-point numerical scoring scale. It is required to examine whether there is a significant difference in the aroma intensity between the two samples. The tabulated scores are given below:

Panelists	*Ginger A*	*Ginger B*
1	3	4
2	6	5
3	4	6
4	5	7
5	7	4
6	6	4
7	4	3
8	5	4
9	4	7
10	7	5

TABLE 9 CRITICAL VALUES OF T IN THE WILCOXON MATCHED-PAIRS SIGNED-RANKS TEST

(*Clause* 6.6.5)

Sample Size (m)	Level of Significance: One-Sided Test, 5 percent	One-Sided Test, 1 percent	Two-Sided Test, 5 percent	Two-Sided Test, 1 percent
6	2	—	0	—
7	3	0	2	—
8	5	2	4	0
9	8	3	6	2
10	10	5	8	3
11	13	7	11	5
12	17	10	14	7
13	21	13	17	10
14	25	16	21	13
15	30	20	25	16
16	35	24	30	20
17	41	28	35	23
18	47	33	40	28
19	53	38	46	32
20	60	43	52	38
21	67	49	59	43
22	75	56	66	49
23	83	62	73	55
24	91	69	81	61
25	100	77	89	68

Here the null hypothesis is that there is no significant difference in the aroma intensity of ginger *A* and *B* against an alternate hypothesis that they are different. The computations for Wilcoxon matched-pairs signed-ranks Test are shown below:

Panelists	*Difference* ($= A - B$)	*Rank of d*	*Rank with less frequent sign*
1	— 1	— 2·5	2·5
2	+ 1	+ 2·5	
3	— 2	— 6·5	6·5
4	— 2	— 6·5	6·5
5	+ 3	+ 9·5	
6	+ 2	+ 6·5	
7	+ 1	+ 2·5	
8	+ 1	+ 2·5	
9	— 3	— 9·5	9·5
10	+ 2	+ 6·5	
		Total	25·0

Since for the panelists 1, 2, 7 and 8, the same difference 1 is obtained, their rank would be $= \frac{1+2+3+4}{4} = 2{\cdot}5$ each. The sum of positive and negative ranks are 30 and 25 respectively. The smaller of the values, that is, 25 is chosen as '*T*'. For a two-sided, the critical value (for m = 10 and 5 percent level of significance) is 8 as obtained from Table 9. Since the calculated value is more than the critical value the null hypothesis that the two ginger samples *A* and *B* do not have significantly different aroma intensities, is not rejected at 5 percent level.

6.6.5.2 *Large Samples* — When the sample size is more than 25, the sum of ranks *T* is normally distributed with:

$$\text{mean } (\bar{x}) = \frac{m\,(m+1)}{4}$$

$$\text{and variance} = \frac{m(m+1)(2m+1)}{24}$$

$$\text{Therefore } Z = \frac{\left|T - \frac{m(m+1)}{4}\right|}{\sqrt{\frac{m\,(m+1)\,(2m+1)}{24}}}$$

is normally distributed with mean zero and variance one. The value of Z is calculated and compared with the critical value of 1·96 (corresponding to 5 percent level of significance) or 2·58 (corresponding to 1 percent level of significance), for a two-sided test. For one-sided test, the calculated value is compared with the critical value of 1·645 (corresponding to 5 percent level of significance) or 2·325 (corresponding to 1 percent level of significance). The null hypothesis is not rejected if the calculated value of Z is less than the critical value.

6.6.5.3 *Example 10* — In a panel test programme on the flavour strength of two grades of the same variety of biscuits, 30 panelists tested each sample on a 9-point scale depending upon their liking. It is required to test whether flavour strength of two grades of biscuits is significantly different. The scores are given below:

Panelists	*Biscuits Grade A*	*Biscuits Grade B*	*Difference d(= A — B)*	*Signed Rank*
1	6	5	+ 1	+ 10·5
2	5	7	— 2	— 25·0
3	5	6	— 1	— 10·5
4	6	4	+ 2	+ 25·0
5	7	6	+ 1	+ 10·5
6	7	8	— 1	— 10·5

Panlists	*Biscuits Grade A*	*Biscuits Grade B*	*Difference* $d(= A - B)$	*Signed Rank*
7	4	7	− 3	− 30·0
8	4	6	− 2	− 25·0
9	5	4	+ 1	+ 10·5
10	6	4	+ 2	+ 25·0
11	6	8	− 2	− 25·0
12	7	9	− 2	− 25·0
13	7	8	− 1	− 10·5
14	8	7	+ 1	+ 10·5
15	8	7	+ 1	+ 10·5
16	6	8	− 2	− 25·0
17	6	5	+ 1	+ 10·5
18	7	6	+ 1	+ 10·5
19	5	4	+ 1	+ 10·5
20	5	4	+ 1	+ 10·5
21	8	6	+ 2	+ 25·0
22	9	8	+ 1	+ 10·5
23	8	9	− 1	− 10·5
24	6	7	− 1	− 10·5
25	4	5	− 1	− 10·5
26	5	4	+ 1	+ 10·5
27	6	5	+ 1	+ 10·5
28	6	5	+ 1	+ 10·5
29	7	9	− 2	− 25·0
30	7	6	+ 1	+ 10·5
			Total	+ 222 − 243

Here the null hypothesis is that there is no significant difference in flavour strength of two grades of biscuits of the same variety against the alternative hypothesis that they are different (two-sided).

In this case T = smaller sum of like signed ranks = 222

$$z = \frac{\left| 222 - \frac{30 \times 31}{4} \right|}{\sqrt{\frac{30 \times 31 \times 61}{24}}} = 0{\cdot}22$$

As the calculated value of Z is less than 1·96, the null hypothesis is not rejected at 5 percent level of significance.

6.7 Range Test — This is a quick procedure to analyse the scoring data in order to study the significance of difference among the samples and if significant which of the sample pairs show significant difference.

6.7.1 The data is first tabulated with panelists in rows and samples in columns. The statistics used are range among the sample totals and the differences within pairs of sample totals. The steps for using range method are given below:

a) The range (R) and total of scores for each sample is computed.
b) The total of sample ranges (ΣR) is computed.
c) The range (R') among sample totals is computed.
d) The product values are computed by multiplying R with the values obtained from Table 10 for a given number of samples and panelists at a chosen level of significance.
e) If R' is greater than or equal to the value obtained in (d), corresponding to the upper tabulated value at 5 percent level of significance, differences among samples are considered significant. If R' is greater than or equal to the value obtained corresponding to the upper tabulated value at 1 percent level of significance, these differences are considered as highly significant.
f) The value obtained in (d) corresponding to the lower tabulated value is compared with the observed differences within pairs of sample-totals at a chosen level of significance. The significance of difference for a pair is determined by the similar procedure as given in (e).

6.7.2 *Example 11* — Five samples of *roti* *A*, *B*, *C*, *D* and *E* were prepared with wheat flours of different particle sizes alongwith a reference sample made from the market flour for assessing difference in the texture. Nine panelists evaluated the texture of the 6 samples on a 9-point quantitative scorecard. The scores are given below:

Panelists	*Samples*					
	A	*B*	*C*	*D*	*E*	*R*
1	6	6	6	5	5	5
2	7	6	5	4	5	5
3	4	6	6	4	3	6
4	6	5	5	5	5	4
5	5	3	5	6	5	5
6	7	6	5	4	6	4
7	7	6	5	6	6	5
8	7	5	5	5	6	5
9	7	7	5	6	5	5
Total	56	50	47	45	46	44

TABLE 10 MULTIPLIERS FOR ESTIMATING OF SIGNIFICANCE DIFFERENCE OF RANGE AT 5 PERCENT LEVEL (FIRST LINE) AND 1 PERCENT LEVEL (SECOND LINE)

(*Clause* 6.7.1)

SAMPLES	PANELISTS 2		3		4		5		6		7		8		9		10	
2	3·43	3·43	1·91	1·91	1·63	1·63	1·53	1·53	1·50	1·50	1·49	1·49	1·49	1·49	1·50	1·50	1·52	1·52
	7·92	7·92	3·14	3·14	2·47	2·47	2·24	2·24	2·14	2·14	2·10	2·10	2·08	2·08	2·09	2·09	2·09	2·09
3	2·37	1·76	1·44	1·14	1·25	1·02	1·19	0·98	1·18	0·96	1·17	0·96	1·17	0·97	1·18	0·98	1·20	0·99
	4·42	3·25	2·14	1·73	1·74	1·47	1·60	1·37	1·55	1·32	1·53	1·33	1·52	1·33	1·53	1·34	1·55	1·35
4	1·98	1·18	1·13	0·81	1·01	0·74	0·94	0·72	0·92	0·71	0·92	0·71	0·94	0·72	0·96	0·73	0·97	0·74
	2·96	1·96	1·57	1·19	1·33	1·04	1·24	0·98	1·21	0·96	1·21	0·96	1·21	0·97	1·22	0·98	1·23	0·99
5	1·40	0·88	0·94	0·63	1·85	0·58	0·81	0·56	0·80	0·56	0·80	0·56	0·81	0·57	0·82	0·58	0·84	0·59
	2·06	1·39	1·25	0·91	1·08	0·80	1·02	0·77	0·99	0·76	0·89	0·76	0·99	0·77	1·00	0·77	1·01	0·78
6	1·16	0·70	0·81	0·52	0·75	0·48	0·69	0·47	0·69	0·46	0·89	0·47	0·70	0·47	0·71	0·48	0·72	0·49
	1·69	1·07	1·04	0·73	0·94	0·66	0·86	0·63	0·85	0·62	0·85	0·63	0·85	0·63	0·85	0·64	0·86	0·65
7	1·00	0·58	0·70	0·44	0·63	0·40	0·61	0·40	0·61	0·40	0·61	0·40	0·62	0·41	0·63	0·41	0·63	0·42
	1·39	0·87	0·89	0·61	0·78	0·55	0·75	0·54	0·74	0·53	0·74	0·53	0·74	0·54	0·75	0·55	0·76	0·55
8	0·87	0·50	0·62	0·38	0·57	0·35	0·55	0·34	0·55	0·34	0·65	0·35	0·55	0·35	0·56	0·36	0·57	0·37
	1·20	0·74	0·78	0·53	0·69	0·48	0·66	0·47	0·65	0·46	0·65	0·46	0·68	0·47	0·66	0·48	0·67	0·48
9	0·78	0·44	0·56	0·33	0·51	0·31	0·50	0·30	0·49	0·30	0·60	0·31	0·50	0·31	0·51	0·31	0·52	0·32
	1·03	0·63	0·71	0·46	0·62	0·44	0·59	0·43	0·59	0·42	0·59	0·42	0·50	0·42	0·60	0·43	0·61	0·43
10	0·70	0·39	0·51	0·30	0·46	0·28	0·45	0·27	0·45	0·27	0·45	0·28	0·47	0·28	0·47	0·28	0·47	0·29
	0·91	0·56	0·62	0·41	0·57	0·38	0·54	0·37	0·53	0·36	0·54	0·37	0·54	0·37	0·55	0·38	0·55	0·38

It is required to test whether the differences among samples are significant and if so which of the sample pairs show significant difference.

Here the sum of ranges (ΣR) is $= 3 + 4 + 1 + 2 + 3 + 2 = 15$.

From Table 10 for 6 samples and 9 panelists, the two pairs of values are 0·71 and 0·48 at 5 percent level and 0·85 and 0·64 at 1 percent level. These values are multiplied by ΣR and the product so obtained is used for determining the significance of difference among the samples and within the pairs of sample totals. Following product values are obtained in this case:

10·65 and 7·20 at 5 percent level, and

12·75 and 9·60 at 1 percent level.

The range (R') among sample totals is 12 ($= 56 - 44$). As R' is greater than 10·65, differences among samples are significant, but they are not highly significant as R' is less than 12·75.

The other two values 7·20 and 9·60 are the minimum differences within pairs of sample totals which should be exceeded to show the significance at 5 percent and 1 percent levels respectively.

By comparing the differences in sample totals for pairs (A, B); (A, C); (A, D); (B, C); ...... with 7·20 and 9·60, it may be observed that sample pairs (A, D) and (A, E) show highly significant difference; pairs (A, R); (B, D) and (B, E) show significant difference and the remaining pairs do not show any significant difference.

6.8 Friedman's Test — In order to test the significance of difference in n related samples with respect to mean ranks, this test can also be used for determining whether rank-sums (or equivalently mean ranks) differ significantly. For this purpose it will be necessary to first convert, the scoring data into ranking data. The details of this test are given in **5.1.3**.

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