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The Modified Friedman Test — A Simple Alternative to the F-test for the Randomized Complete-block Design[1]

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Horticulturalists frequently use the analysis of variance (F-test) to determine treatment differences. Many simple non-parametric tests, which require fewer assumptions, are also available. This note presents an example of the modified Friedman test as an alternative analysis for ranked data from a randomized complete-block design.

Parametric tests, such as the F-test, required that samples from all treatments be randomly drawn from a normally distributed population with a homogeneous variance. If normality and homogeneity assumptions are not checked and satisfied, the significance level for the F-test and the conclusions of treatment differences may be affected. Some statisticians consider the robustness of the F-test compensates for deviations from normality or homogeneity which may occur in the data. Bradley discusses the "Myth of Robustness" (1). He wrote, *"Furthermore, although the two-tailed, two-sampled t-test is a special case of the analysis-of-variance F-test, the perfect robustness of the former against heterogeneity of variance when sample sizes are equal and infinite does not extend to the latter in the general case".* The F-test or any statistical test is a valid test only if the requirements of the test are satisfied. These requirements or assumptions should be checked for every set of data. Even if the data meets the requirements for a valid F-test, multiple comparison procedures are often misused (2,7).

Transformations of the data may satisfy the assumptions of normality and homogeneity of variance for the F-test. The exact transformation depends on the data. Ranked data after transformation may be analyzed with the F-test (1,3).

Non-parametric tests, like parametric tests, require that the samples be randomly drawn from the population of interest. Non-parametric tests, unlike parametric tests, do not require normally distributed data or homogeneous variances. In experiments where data are ranked but not further quantified, e.g., stem sections ranked in order of increasing injury following freezing, non-parametric tests are appropriate analyses. The type of data dictates the appropriate non-parametric test of the many that are available.

Several statisticians have prepared tables which enable the researcher to accurately select the correct test for a given data set. Darlington (4) has an elementary introductory test. Meddis (6) provides a simple, relatively non-mathematical guide. Conover (3) presents more complicated tests with good explanations of their limitations. These books are readily usable as statistical references by horticulturists familiar with Steel and Torrie (9) or Snedecor and Cochran (8).

The modified Friedman test is a powerful non-parametric test for a randomized complete-block design using ranked data (3). As with the usual F-test, and most statistical tests, the samples must be drawn at random from the populations of interest. We have used the modified Friedman test to detect differences in cold hardiness of cultivars exposed to controlled freezing.

For the modified Freidman test, all samples in each block must be ranked and each treatment must have the same number of samples per block. Like the F-test, samples must be randomly assigned to treatments in each block. Numerical data, such as percent germination, injury, bloom, etc., can be easily convertes to ranks. Categorical data, e.g. data classified as uninjured, some injury, severe injury, and dead, with a limited number of observations per block, could be ranked by the researcher when originally recorded. Sensitivity of the test increases if groups that result in no treatment differences are deleted before analysis. For example, if in a test of disease resistance, all plants are killed at one site, results from that site provide no information about relatively disease resistance.

The example in Table 1 explains the analysis procedure. Four grape cultivars (treatments) are under trial for date of bud burst in each of 2 different vineyards (blocks), and 3 plants of each cultivar are selected at random from each vineyard. The amount of bud burst is ranked for all plants at each vineyard (Table 1).

The equation for testing differences between cultivars is:

$$T = \frac{12}{bcm^2\,(mc+1)} \sum_{i=1}^{c} R^2 - 3b\,(mc+1)$$

Where:

b=Number of blocks.
c=Number of cultivars.
m=Number of observations per block for each cultivar.
R_i=Sum of ranks i-th cultivar.

For the example:

$$T = \frac{12[(17.5)^2+(46)^2+(45.5)^2+(47)^2]}{2\times4\times3^2\,(3\times4+1)}$$

$$-3\times2(3\times4+1) = 7.92$$

In the example, the probability of having a larger value of T by chance is less than 5% (df=3). The test statistic (T) is distributed approximately as chi-square with c-1 degrees of freedom. For the example, we conclude the four cultivars are not all at bud burst on the same date.

Rejection of the null hypothesis

Table 1. Ranks of amount of bud burst for 4 cultivars at 2 blocks on a single date. Ties receive the mean rank.

Block	Ranks			
	Foch	Concord	Aurore	Vidal Blanc
1	1,2,4.5	3,9,10	4.5,8,12	6,7,11
2	1,3,6	5,8,11	2,7,12	4,9,10
Sum of ranks	17.5	46	45.5	47

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made us interested in further comparisons among the cultivars. Further comparisons are possible by repeated application of the test to a reduce number of treatments. Unfortunately, the comparisons are not independent and the significance level of the test changes in an unknown way (3). Though the probability level is not exact, treatment differences can be investigated. If the null hypothesis is rejected, the original sums of ranks are ordered and contiguous sums of ranks selected. Data for the reduced numbers of treatments would be re-ranked and the modified Friedman test applied to the new sums of ranks. For our example, Foch differs from the other three cultivars.

To illustrate the sensitivity of the Friedman test, given 1 plant from 3 treatments in 3 blocks, the treatments are different at the 5% probability level if the cultivars are ranked in the identical order for all 3 blocks. Several authors give the exact distribution of T for 3 treatments with 2 to 15 blocks and 4 treatments with 2 to 8 blocks (1,5). The chi-square approximation tends to be conservative (3). Conover gives several modifications of the Friedman test, including an extension to the incomplete block design (3).

The modified Friedman test is an easy test for analyzing ranked data from a randomized complete-block design. Using this test, quantitative data may be analyzed without checking the assumptions of normality of homogeneity of variance. We encourage horticultural researchers to check assumptions and use tests appropriate to their data. Non-parametric tests provide simple, adequate analyses in many experiments where a F-test is unnessary or inappropriate.

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In Vitro Propagation of *Kalanchoe*[1]

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We have achieved a rapid (4-6 weeks from culture initiation to potted plantlets) *in vitro* method for clonal propagation of *Kalanchoe bossfeldiana* Poelln. The resulting potted plants have increased branching and shorter internodes than plants established by conventional propagation methods, making them commercially desirable. This *in vitro* method has potential for rapid propagation of new *Kalanchoe* cultivars, as each leaf, shoot tip, and stem section could be used as an explant for culture. This plant is widely available and is ideal for classroom demonstration of tissue culture.

Leaves, stem sections, and shoot tips were excised from greenhouse-grown plants and washed in warm, soapy water, rinsed, surface sterilized for 10 min in a 15% (by volume) solution of sodium hypochlorite plus 2 drops/100 ml of the surfactant Tween-20, and then rinsed 3 times in sterile water. Sections of leaf blade (15 × 15 mm), stem (15-20 mm) and shoot tips with 2-4 primordial leaves (1-2 mm) were placed in culture and incubated in 16 hr photoperiod (20 $\mu Em^{-2}s^{-1}$) at 27 ± 2°C.

Initial comparisons were made between agar-solidified and stationary liquid medium in which the explant was supported on a filter-paper platform. The culture medium for all experiments contained Murashige and Skoog inorganic salts (1) and in mg/liter: myo-inositol, 100; adenine sulfate·$2H_2O$, 80; thiamine·HCl, 0.4; $NaH_2PO_4 \cdot H_2O$, 120; sucrose, 30,000; indoleacetic acid (IAA), 1.0; kinetin, 1.0; and Bacto-agar, 6,000. The pH was adjusted to 5.7 prior to autoclaving 15 min at 121°C.

Root initiation was tested with the above basal medium and 0, 0.5, 1.0, 2.0 mg/liter indolebutyric acid (IBA) and napthaleneacetic acid (NAA) at 0, 0.5, 1.0, and 2.0 mg/liter in the absence of kinetin. Ten to 20 explants were cultured per treatment.

Within 3 weeks, bud and shoot initiation occurred from leaf, stem, and shoot explants. The average number of plantlets per culture tube at 4 weeks was: 35, stem (liquid); 25, stem (agar); 33, leaf (liquid); 60, leaf (agar). Leaf cultures on agar-solidified medium gave the best plantlet formation. Shoot formation could perhaps be increased by other cytokinins at different concentrations. Shoot tips were then tested against leaf segments on agar-solidified medium. Shoot tips gave 60-100 plants/tube, and appeared to be a preferred explant source (Fig. 1). In addition, where leaf segments served as an explant source there was a 10-20% contamination rate as compared to 0% for shoot tips.

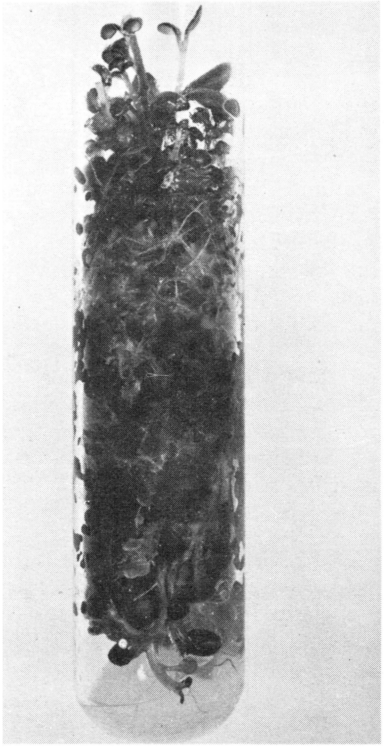

Fig. 1. *Kalanchoe* shoot tip after 5 weeks in culture.

Shoots formed roots on all IBA levels tested, but best root and shoot development was achieved at 1 mg/liter. Rooting was reduced at all levels of NAA. *Kalanchoe* shoots with or without roots were directly transplanted to Redi-earth in 1.9 cm^2 seedling flats under 2 layers of shade cloth in the greenhouse with 99% survival.

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