Nondestructive Quality Evaluation of Agricultural Products: A Definition and Practical Approach

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ABSTRACT

A definition of terms in this research area is presented. A general approach for applying nondestructive quality evaluation (NDQE) to horticultural crops, for both fresh and processing purposes is discussed. The approach includes consideration of the importance of biochemical, morphological and physical parameters of quality. The objective and subjective determination of single and multiple parameter judgements of quality at different stages of physiological development is a critical part of this approach. The concept of "Optimum Quality Range" is presented in relation to the development of nondestructive quality evaluation techniques and applications.

In approaching the subject of nondestructive quality evaluation (NDQE) of agricultural products, one should appreciate that man has always made this type of judgment. Historically, the color and texture of fruits and vegetables have been evaluated by eye and by feel without destroying the integrity of the product. A formal research approach to NDQE includes basic research to define quality, to develop and compare methods of measuring quality, to develop highly specialized instruments, and to study the practical applications of this analytical approach in the total food delivery system. This approach has received increased interest and support in the last two decades. In my opinion, it deserves recognition as a research area with a great deal of potential for valuable practical applications. The potential value of this work was the basis for planning this symposium.

THE TERMS

In setting the stage for this symposium, there is need to define the terms "nondestructive," "quality," and "evaluation." The term "non-destructive" indicates that the sample, (the physical form is not critical), can be analyzed and meaningful data collected by some means so that the physical and chemical attributes of that sample are not altered. The sample can then be used for other purposes, such as eating. The word "quality" has several meanings, but I believe the one we are looking for is "The degree of excellence which a thing possesses; hence, excellence or superiority." Another more basic definition of quality is "that which makes something what it is." "Evaluation" means "to determine the worth of; to appraise." Putting these three words together, nondestructive quality evaluation could be simply stated as "the gaining of meaningful information that can be used in making judgments, both positive and negative, about the degree of excellence of a food without altering the physical and chemical properties of that food."

The methods of obtaining these objective analyses by nondestructive means include weighing, sizing, spectrophotometric analysis by reflectance or transmittance measurements, X-ray analysis, the use of sonics to determine some degree of tissue integrity, and densiometric measurements using light, liquid, or possibly radiofrequencies.

QUALITY FACTORS

One of the purposes of this presentation is to give a general approach for the application of NDQE to agricultural products with emphasis on horticultural crops. In keeping with this approach the first step should be selection of the positive quality factors that are critical for a specific commodity.

For example, man considers most apples to be red, peaches to be yellow-orange, some avocados to be green colored when ripe, and tomatoes to be red, in general. The fact that color varies from commodity to commodity has not deterred man from using that parameter as an index of quality.

A second quality factor is flavor. Flavor is a subjective judgment but has a number of objective components which include sugar content, acidity, the amount and type of volatile compounds, and the presence or absence of materials that contribute to astringency or bitterness.

A third quality factor is texture. It is generally accepted that celery should be crunchy, peaches and cantaloupes should be firm to soft but not mushy,
avocados should be soft, and snap beans should be free from an excessive number of fibers. These textural properties can be evaluated by means of a shear press, but that is destructive. Density or optical measurements may prove to be important in this area. Some evidence indicates that light-scattering measurements might be useful in assessing texture.

These three attributes (color, flavor, and texture) are generally positive. Attention must be given to negative quality factors—defects. Characteristics in this category include bruises, cuts, insect bites, diseased or rotted areas, brown or black spots, and flower parts. Any factor that detracts from the final product quality grade can be measured by classic chemical analyses which are, for the most part, destructive. This approach can be illustrated by the changes in physicochemical properties of pineapple fruit during the period from flowering to senescence (Fig. 1).

**MEASURING CHANGES IN QUALITY FACTORS**

After considering the above quality factors and selecting the specific quality parameters for a commodity, the next step is to determine changes in these parameters between different stages in the development of the fruit or vegetable. The changes usually are measured by classic chemical analyses which are, for the most part, destructive. This approach can be illustrated by the changes in physicochemical properties of pineapple fruit during the period from flowering to senescence (Fig. 1).

![Changes in physicochemical properties of pineapple fruit during period from flowering to senescence. From Gortner et al. (2).](image1)

As defined by Gortner et al. (2), development is the period from the end of blossoming to and including the ripening of the fruit. A subdivision of this development time is the precultivation period, which is the developmental period before onset of maturation processes and generally includes at least half of the interval between blossoming and harvest. Maturation covers the stage of development during which the fruit emerges from the incomplete stage to attain a fullness of growth and a maximum edible quality. Ripening is the terminal period of maturation during which the fruit attains its full development and its maximum aesthetic and edible quality. Senescence is the period following fruit development during which growth has ceased and the biochemical processes of aging replace the perfective changes of ripening.

The critical factor in this approach is to recognize that each time a fruit is produced, it goes through a predictable series of compositional changes. It reaches a predictable endpoint, a ripe fruit. It is these changes during development which are of concern in the application of nondestructive quality evaluations.

Using pineapple as an illustration, note (Fig. 1) that during prematuration and the early part of maturation, chlorophyll is high, meaning that the fruit is very green in appearance. During the latter stages of maturation or ripening, there is a rapid degreening of the fruit. This trend is characteristic. During the ripening stage of pineapple the flesh Brix (a measure of soluble solids which are primarily sugars) increases markedly. This increase is interpreted by man as an increase in sweetness. The acidity has an interesting change since it reaches a maximum just before the fruit becomes ripe, and then it decreases. This is a moderating effect and the fruit is less tart. The fruit color changes in two ways. It degreenes through a loss of chlorophyll, and the yellow becomes more intense due to the increase in the amount of flesh carotenoids during ripening. This increase continues into senescence. The esters show a marked increase in the last few days of ripening from basically zero to a very high level (over 100 ppm). These are examples of selected quality parameters which are dynamic in their changes. These sophisticated measurements are really of little value unless they are related to human judgments or choices of quality.

The concept of optimum quality range (OQR), introduced by Dull and Hulme (1) offers a way to understand the interrelations of objective and subjective measurements of quality. The concept of OQR is presented graphically in Fig. 2. Although Fig. 2 is based on data developed with pineapple and a panel of 50

![A generalized presentation of changes in percent acceptance as ripe for fruit during the period of flowering to senescence. The crosshatched area represents the Optimum Quality Range.](image2)
people, the concept is considered applicable to fruits in general. Time from flowering until ripeness is represented on the X axis, and percent acceptance on the Y axis. In developing the panel, two questions were asked. First, do you know what a pineapple is? Second, do you like pineapple fruit? If both questions were answered affirmatively, the person was qualified to serve on the panel. This approach is concerned with acceptance rather than preference.

After the panel was constituted, a sampling schedule was established and samples were collected, prepared, and presented to the panel. The panelists were asked, “Do you accept this sample as characteristic of a ripe fruit?” The response had to be either yes or no.

At the flowering stage, no one said the fruit was acceptable as ripe. Proceeding along the time axis at selected sampling dates, responses continued to be of zero percent acceptance as ripe until one point, an individual said “Yes, this fruit is ripe.” At the next sampling more panel members said “Yes, this fruit is acceptable as ripe.” At one point on the time axis all of the panel said “Yes, I accept this fruit as ripe.”

Continuing on the time axis, a point was reached at which some panel members did not accept the sample as ripe. The connotation was that the fruit had entered senescence and so was considered over-ripe and therefore not acceptable.

To delineate the 70% acceptance range, a line was drawn at the 70% acceptance level to intercept the curve on both the positive and negative slopes. The time between these two intercepts was designated as the 70% acceptance range or the optimum quality range (OQR). The 70% value is arbitrary and would be subject to the judgment of individual researchers. Within the OQR, fruit have specific ranges in composition. In illustration of this point, for pineapple expected ranges would be 8 to 15% for brix, 0.6 to 1.1% for acids, 10 to 100 ppm for esters, and 0.4 to 1.2 ppm for yellow pigments.

Physiological development is an ongoing process from flowering to senescence during which any point can be called a stage of development. In the idealized situation all fruit at the same stage of development would have the same chemical and physical properties. The OQR can thus be viewed as a continuum of stages of physiological development, all of which are acceptable as ripe for the fruit population being evaluated. Saying it in another way, in a given population (fruit from the same field) all fruit at the same stage of physiological development could be expected to have similar compositions.

If fruit were selected from different populations, e.g., a different field or a different year, the OQR could still be described, but the absolute values for the ranges might differ. For example, a ripe fruit in Field 1 may have a sugar level of 12% and an acid content of 1.0%. In Field 2, a ripe fruit may have 14% sugar and 0.6% acid. Based upon the judgment of panelists, both fruit could fall within the OQR, but they would taste very different.

A more familiar example is the wine grape. Based upon accepted quality parameters, there are good and bad grape years. All wine grapes are picked at the peak of their physiological development each year, and that peak composition is the best that can be obtained from that field that year. The peak composition can be expected to vary from year to year.

Moving towards the application of NDQE to horticultural crops, another point needs to be raised: more than one quality parameter may be needed to make the final maturity or quality index judgment. In pineapple, the amount of light (at 468 nm) transmitted through a sample has been measured. When transmittance was correlated with chemically measured pigments in the same tissues, the coefficient of determination ($r^2$) was relatively low, in the range of 40% for some samples. It became obvious that the samples, for which the correlation was low, had an opaque appearance indicating there was air in the interstitial spaces. This opacity was measured by illuminating the same sample with white light from a tungsten bulb and using a selenium photovoltaic cell to detect radiation which passed through the sample. By simple calculation of the square of absorbance at 468 nm, times the instrument reading of the photovoltaic cell output, a pigment index was derived. This index, when correlated with the pigment measurement, gave an $r^2$ value of 74. Thus, a two-parameter measurement was necessary to estimate pineapple pigments nondestructively. An example of a three-parameter measurement for maturity index would be the simultaneous determination of color, density, and size in peaches.

**INSTRUMENTAL QUALITY MEASUREMENT**

Although extensive research has already been conducted on how to determine quality factors of agricultural products nondestructively, more effort in this area is necessary. The papers following will address this subject more specifically. The NDQE sensing of specific quality parameters of horticultural products in the context of automatic high speed sorting is an accomplished fact. The number of specific applications continues to grow. After developing an instrument system for sensing quality for a given commodity, it seems logical to move on to practical applications—the prototype sorting machine. This is not to be confused with a commercial unit which handles commercial quantities of product, but is really a pilot plant model in which the sensing operation can be combined with several handling operations, such as unloading, washing, singulation, and disposition. Each of these steps could be expected to influence the validity of the specific NDQE measurements. For example, after a “best” means of sample presentation has been ascertained, considerable work can still be required to actually affect that sample presentation in a pilot plant sorting unit.

In considering a prototype sorting unit we should recognize that the speed of the sensing operation is not likely to be the limiting factor. The combined sensing,
calculation, and decision-making operation can be accomplished in milliseconds. However, the operations of singulation (the transformation of a stationary group of fruit into a moving line of separated fruit) and disposition (the movement of a fruit from a moving line of separated fruit to an area established for fruit of similar quality) pose interesting challenges. They must be accomplished with minimum damage to the product and maximum accuracy of quality evaluation. In terms of accomplishing the high speed separation of fruit based on NDQE, the operations of singulation and disposition are as important as the sensing operations.

In addition to the concern with problems of high velocity handling of fruit, there is also a need to be concerned with the problems of evaluating an entire fruit, as opposed to a small portion of the surface. The filling of this need is difficult because of fruit size, irregularities in shape and surface, and inherent variations in the composition of different parts of a single fruit. Allowances for this consideration must be designed into the prototype sorting unit as required.

The complexity of the sorting unit could increase even more if there were a need to examine small areas on the surface of a fruit. This need could hinge on the relative importance of specific defects such as cuts, bruises, insect bites, and brown or black spots.

Our present day knowledge of electronics technology, chemical analysis, physiochemical properties of foods, computers, and produce handling technology is highly sophisticated. We do have the capability of making rapid (millisecond) judgments on the quality of soft flesh products (peaches, blueberries, apples) as well as the capability of handling large quantities of products at rates that are commercially feasible and acceptable.

We have before us an open door. As we look behind us, we see a considerably greater amount of application of nondestructive quality evaluation today than we had a decade ago. Through the door we see a much greater appreciation for the application of NDQE in the future. I look forward to moving through that door with you and to our success in bringing NDQE to a high level of acceptance and application.

REFERENCES
