Nondestructive Quality Evaluation  
From a Horticulturist’s Point of View  

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ABSTRACT  

Application of nondestructive sorting of fruits can be direct or indirect. Direct applications involve mainly objective means of establishing grades and quality of fruits and vegetables, as well as use of light-sorting and other nondestructive means for determining when a crop should be harvested or whether it should be marketed fresh or processed immediately. Indirect applications might be termed “research” usage of nondestructive sorting. Plant breeders would find nondestructive techniques useful for rapidly evaluating quality characteristics during the development of high quality cultivars. Physiologists could utilize it to rapidly determine the effects of treatments upon the quality of the commodity. Examples of development of techniques of light-sorting of blueberries and grapes for ripeness are discussed.  

From a horticultural standpoint, the potential of nondestructive sorting of horticultural crops for quality is truly exciting. Applications can be seen as both direct and indirect. Direct refers to its commercial use in determining grades and standards. Since the inception of our present inspection system in the 1920’s, most of the quality characteristics of fruits and vegetables have been estimated subjectively by the inspector. This is done amazingly accurately by eye, touch, etc. However, development of accurate, rapid, and objective means of measuring quality would be of great value to the inspection system. After proper estimators (non-destructive) of maturity and quality for each product (often for the particular cultivar) have been determined by researchers, these objective estimators can be used as grade standards. For example, internal and external color can be described in terms of which color-sorting machine settings are used to sort a crop in the packinghouse. Also, the uniform ripeness of a given lot of fruit coming into one of many hoppers from a light-sorter machine can, in many instances, be rapidly and easily categorized by determining the soluble solids to acid ratio (SS/Ac) of one or two small random subsamples of that lot of fruit. Sol-
quality characteristics such as sugars, proteins, starch, fiber, and lignin can perhaps be determined nondestructively. Research on dried forage and dried tobacco so far looks promising.

OUR EXPERIENCE

We, as post-harvest physiologist, plant breeder, agricultural engineer, or enologist at North Carolina State University have worked in one way or another with quality of highbush blueberries and muscadine grapes for a number of years. Thus, we have for some time been keenly aware of the need for developing objective means of nondestructive sorting fruits of quality. Some 10 years ago, L. J. Kushman, formerly of USDA-ARS, working with researchers Karl Norris and Gerald Birth, brought light-sorting to the small fruit industry in North Carolina. Our first work was undertaken with an instrument called the Light Transmittance Difference Meter (LTDM), developed by Birth and Norris (5). That was the beginning of our rewarding adventures in nondestructive sorting. Our first work was to investigate the implications and relationship of light-sorting to highbush blueberries.

Blueberries

Until recently, blueberries were picked by hand. A person looked at the blueberries on a bush and made a decision as to which berries should be picked. Blue fruit were picked directly into pint boxes for shipment to market. Green, red, and purple fruit were left on the bush for subsequent harvest. Little work in the packinghouse was necessary. However, the recent expense and scarcity of labor has resulted in development of mechanical harvesters which are non-selective in removal of berries from the bush. These machines harvest bulk quantities of fruits representing the full range of ripeness from small-green to overripe-blue. This results in a tremendous problem of sorting for ripeness in the packinghouse. There the human eye can easily and quickly detect green fruits going by on a conveyor belt of a sorting/packing line but cannot easily differentiate between an all blue fruit is “just ripe”—one that is blue and “overripe.” Thus, small green fruits can be removed by sizing, air blast, or by hand, but overripe fruit cannot. Inclusion of these overripe fruits in fresh market packs presents a problem. Overripe blueberries (SS/Ac greater than 30) decay very quickly and therefore should be processed immediately while quality is high (U). Just ripe blue fruit have a longer shelf/storage life and are more ideally suited for fresh marketing. Green fruit are not acceptable in the fresh market trade but perhaps could be processed along with overripe fruits into products such as pop-tarts. Thus, we were interested in developing a means of rapidly, effectively, and nondestructively sorting blueberries for ripeness before they are packaged for shipment to fresh markets or are sent to processing plants.

Development of a light-sorting technique was begun by selecting unripe and ripe blueberries of the North Carolina cultivars Wolcott, Croatan, Murphy, and Morrow, using subjective criteria of skin color, degree of oblateness, and distention of stem scar. These berries were carried to Beltsville, MD to Mr. Karl Norris in the USDA’s Instrumentation Laboratory. There, the spectral curves (600-850 nm) of these berries were determined on the spectrophotometer (3, 7, 8, 10). From these curves, we selected two pairs of wavelengths (710-800 and 740-800 nm) such that the Δ OD for a given pair of wavelengths changed progressively as the berries changed in ripeness. Filters for these wavelengths were purchased and installed in the LTDM borrowed from Dr. Watada, USDA-ARS, to test-sort several lots of blueberries into categories of “Fourth OD”. Destructive estimations of pH, titratable acidity (Ac) (% as citric), % soluble solids (SS), SS/Ac, and anthocyanin (Acy) content of those sorted berries were determined analytically. The wavelengths 740-800 nm were more effective in sorting according to ripeness than were the wavelengths 710-800 nm. Correlations of Acy contents and Δ OD (r = 0.94) of Ac and Δ OD (r = −0.82) of these fruits indicated that the LTDM (740-800 nm) did indeed sort blueberries according to ripeness. These results supported those reported earlier by Dekazos and Birth (6).

However, sorting with the LTDM was slow. Six people relieving each other could sort only 2,000 berries during a 10-h day. Each berry had to be placed on the machine before lowering the photomultiplier-tube assembly; the voltmeter had to be read, and the berry then had to be placed manually in one of several boxes, each marked with a given range of Δ OD (category of ripeness). This was tedious. A high speed sorter was essential if we were to undertake experiments requiring large numbers of optical determinations.

Therefore, over 5 years ago, working in cooperation with agricultural engineers, we established design criteria for development of a semi-automatic sorter which has come to be known as the “Berrymatic” (9). This machine sorts small fruits (blueberries, grapes, etc.) into five categories of ripeness at a maximum rate of 64 berries per minute. Berries are placed on 16 cups on a rotating horizontal disc. An aperture in the bottom of each cup permits light from a stationary incandescent lamp to strike the bottom of a given berry as the berry and cup pass over the lamp (reading station). Each fruit, being an excellent diffuser, then glows like a low wattage lamp. Sufficient light is scattered from the berry in all directions to permit fibre optics to be offset from the vertical. This prevents saturation of the detection system on the other end of the bifurcating fibre optic bundle when a fruit is not in the cup.

Each fruit is thus "read" as it traverses the light/reading station. A portion of the light transmitted through the berry is transmitted by the fibre optics to each of two narrow-band interference filters (740-800 nm for blueberries) covering each of the bifurcations of the fibre optics. Two red-sensitive photomultiplier tubes detect the energy transmitted through the filters. The "reading" from each fruit is stored in an electronic shift register until the fruit moves to one of five sorting stations, as established by the reading. One of five solenoid valves is activated to release a compressed air blast that removes the berry from the sample wheel and sends it into one of five sample boxes at the rear of the machine. In the Berrymatic, the larger the reading, the riper is the fruit. Thus, the machine reads, stores the reading, and sorts the berry at the appropriate time into one of five categories of ripeness.

Using this machine, over 10,000 berries can be easily sorted on a given day. For example, over 20,000 berries were sorted to set up a blueberry storage test involving 216 one-hundred- berry samples, five stages of ripeness, three storage temperatures, and six sampling dates. The test's objective was to determine the effect of stage of ripeness on the storage life of blueberries at 1.1, 10, and 22.2 °C. Results of the test indicated that blueberries held at 22.2 °C decay quickly regardless of stage of ripeness. The real economic benefit of sorting blueberries for ripeness was realized when the fruits were stored at 1.1 °C. Just-ripe blueberries (SS/Ac 9) required 35 days to develop 20% decay as compared to only 16 days for overripe blueberries (SS/Ac 32). These findings hopefully should introduce the fresh market trade to the extreme importance of sending only just-ripe blueberries to transoceanic markets where up to 10 days are required for transport. The high cost of transportation dictates that only the highest quality fruit be shipped.

Grapes

Our work with nondestructive sorting of muscadine grapes (Vitis rotundifolia Michx.) was prompted by our grape breeder, Dr. W. B. Nesbitt. He desperately needed a rapid, non-destructive means of eliminating the ripeness variable from his evaluation of quality characteristics of the fruit in his grape breeding program. He tried specific gravity (citric acid, sucrose, or sodium chloride solutions), firmness (Instron Universal Testing Machine), and similar techniques. The specific gravity and firmness methods worked, but were considered too slow and "messy."

A cooperative effort was then put forth to evaluate the potential for light-sorting his grapes. We hoped that we could utilize the Berrymatic that was developed for the blueberries. Again, a series of grapes ranging from green to overripe was chosen subjectively according to firmness by touch, degree of visual surface gloss, and external visual coloration. Since muscadine grapes include cultivars that produce berries that are either bronze or black in color when ripe, a series of ripenesses was selected for each of these types and taken to Mr. Karl Norris' laboratory in Beltsville, MD. There, spectral curves from the sets of fruit were developed. These fruits were then returned to Raleigh, NC where pH, Ac, SS, and SS/Ac were determined destructively in the analytical laboratory. Correlations of Δ OD and SS/Ac (r = +0.92), Δ OD and SS (r = +0.90), and Δ OD and Ac (r = -0.89) indicated that the pair of wavelengths (540 and 610 nm) had potential for use in light-sorting of bronze muscadine grapes. For black grapes, the 740-800 nm wavelengths, as used for sorting blueberries, were selected. We subsequently sorted large quantities of both types of grapes into several stages of ripeness using the Berrymatic (2). Subsequent destructive testing of these grapes for ripeness confirmed our selection of wavelengths.

A further confirmation of the effectiveness of light-sorting into categories of ripeness was obtained by a recent study of the effect of ripeness of grapes upon the quality of wines made from the grapes.

FUTURE OUTLOOK

Thus far, we have developed techniques for non-destructive sorting blueberries and grapes for ripeness. We have developed a semi-automatic Berrymatic TM sorter for use in our research programs. Currently, we are developing an in-line light-sorter to mass sort blueberries rapidly. A second-generation, breadboard model was evaluated last summer. It sorted 400 berries per minute using fibre optics and electronics similar to those developed for the Berrymatic. It has five sorting channels, each of which can sort into three categories: green, ripe, and overripe. Continued success in its development can hopefully provide a commercially available in-line sorter within a few years.

We are greatly encouraged by our success in light-sorting thus far and hope to develop similar techniques for other crops. Thus, an inter-disciplinary research project has been initiated at North Carolina State University. A computerized biological spectrophotometer of our own is being established. It consists of a Cary 17 Monochrometer, a Nova 2/10 Computer with 325 words of memory, a 3-Drive Cassette Tape, a Model 611 Tektronic Scope, Teletype, an X-Y Plotter for Hardcopy of Spectra, and a Model 306 Centronic Printer. It has a scan range of 0.4 to 3.0 nm. A silicon detector can be used to scan from 0.4 to 1.0 μm; a lead sulfide detector can scan from 1.0 to 3.0 μm. It is blazed at 1.6 μm for high efficiency in near infrared. Resolution is 0.01 nm. We are truly excited about the potentials of nondestructive sorting.

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REFERENCES


