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Horticultural Maturity Revisited: From Peaches to *Echinacea*

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ABSTRACT

A considerable amount of research has been conducted on defining maturity indices for horticultural products that ensure that these are harvested at their horticultural maturity. It is at this stage of development when a plant or plant part has met the conditions for utilization *for a particular purpose*. For fresh-market produce, horticultural maturity is based on the final assessment by the consumer based on the product's sensory characteristics. For produce that is to undergo processing, horticultural maturity is set based on how produce at various stages of development will tolerate extreme conditions during processing. Horticultural maturity for both fresh-market and processing commodities relies heavily on the consumer's quality judgment and that is why sensory evaluation constitutes the most powerful way of defining maturity indices for these two market venues. With a growing body of evidence supporting the role of plants in human disease prevention or intervention, it becomes critical to define valid models for establishing maturity indices for plants harvested for these purposes. In the present manuscript, we report the use of phytochemical markers as well human gene expression as parameters that help establish appropriate harvest windows.

Keywords: botanicals, harvest indices, harvest window, herbs, maturation, phytochemicals

INTRODUCTION

Horticultural products include a variety of commodities including fruit, vegetables, spices and herbs. Typically, horticultural products can follow two commercialization channels: fresh market or processing. Processing, which seeks to preserve or extract key components of a commodity, can range from complex unit operations such as canning or juicing to minimally processing. More recently, a third option has been added to the commercialization of horticultural products, which can be transformed into value-added *nutraceuticals*. According to Merrian-Webster nutraceuticals can be defined as: "a foodstuff (a fortified food or dietary supplement) that provides health benefits."

The delineation among the three channels is not related to the commodity but to the intended use. For example, oranges can either be sold in the fresh market, or processed as juice, or used as a raw material in the extraction of citrus flavonoids. Likewise, tomatoes can be sold as fresh produce, or processed as a canned product or juice, or used as a raw material in the extraction of lycopene.

It is important to recognize, however, that the intended use dictates when a commodity should be harvested. According to Reid (1992), "horticultural maturity is the stage of development when a plant or plant part possesses the prerequisites for utilization by the consumer *for a particular* purpose." Based on this premise, it is likely that the horticultural maturity for a given commodity will be different depending on its intended use. Regardless of commodity or intended use, the protocol to determine horticultural maturity and maturity indices remains the same. **Fig. 1** provides a graphic depiction of this protocol. **Maturity indices** (also known as harvest indices) are the parameters chosen to identify when a commodity has reached horticultural maturity. The **decision end-point**, on the other hand, is the criterion (or criteria) by which the commodity will be judged to be suitable for its intended use.

MATURITY INDICES: IN SEARCH OF THE BEST SIGNS OF MATURITY

As a commodity moves towards horticultural maturity, there are many physiological and compositional changes that take place in the plant. These changes, which may include increases in size or mass, hormonal variations and alterations in the metabolism of carbohydrates, pectins, organic acids, pigments and a variety of phytochemicals, vary for different commodities. Furthermore, while some commodities show pronounced visual and/or textural changes during the process of maturation, others show only minor differences in appearance.

The determination of maturity indices relies on the changes that take place in a commodity as it matures. From all changes, it is the ones that best correlate with the decision end-point (chosen *a priori* in the process of maturity index determination) that should be considered as possible maturity indices. In a developmental study of lemon fruit, it was found that the age of the fruit had an influence on the physical characteristics of fruits of different flushes. Fruit growth followed a sigmoid pattern and juice accumulation significantly increased with the age of the fruit. Specific gravity and peel thickness, on the other hand, gradually declined with age, but without a pronounced trend (Sema and Sayal 2003). In a maturation study of mango cv. 'Gogshall,' it was reported that fruit fresh mass, density, and pulp dry matter can be useful indicators of when to harvest the fruit (Lchaudel and Joas 2006).

Several compositional features are also commonly used as maturity indices. In many fruit, the decline in the concentration of chlorophyll is a useful indicator of maturity. Sanu *et al*. (2006) reported that time-resolved reflectance spectroscopy is an effective means of segregating 'Ambra' nectarine fruit by chlorophyll concentration, which in turn correlates with the sugar and acid content of the fruit. In fruit with completely red-pigmented peel, such as certain peach or apple varieties, chlorophyll is masked by anthocyanins.

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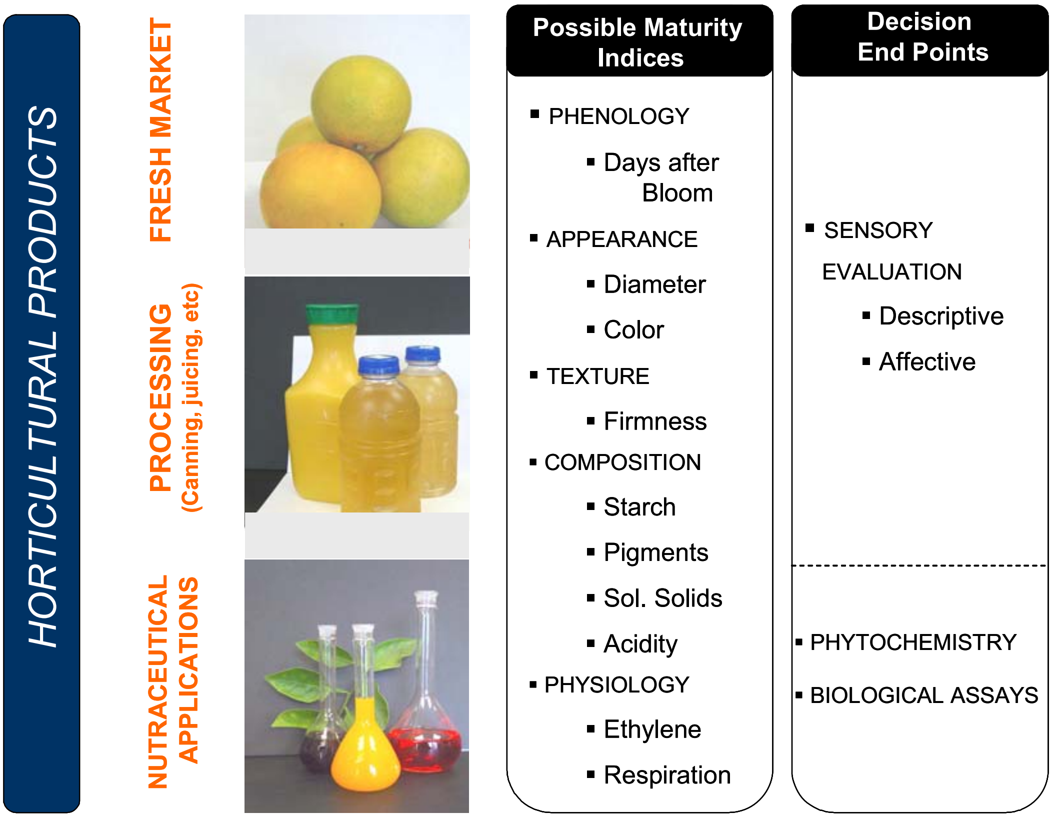

Fig. 1 The following protocol takes into account the intended use of the horticultural commodity in order to select a path for the determination of an appropriate maturity index.

In these fruit, fluorescence imaging has been found to correlate with chlorophyll content regardless of the type of fruit or anthocyanin content (Bodria *et al*. 2004).

Changes in soluble solids and acidity were assessed during maturation of 'Satsuma' mandarin. Changes in these two parameters were dependent not only on maturity, but on the region of the fruit where they were measured (Moon and Mizutani 2002). Soluble solid measurement by refractometry is often used a maturity index. This measurement, however, should not be equated to sugar content (as demonstrated for sweet corn by Hale *et al*. 2005) or sweetness (as shown for strawberries by Kader *et al*. 2003). Likewise, the commonly used starch iodine method should not be construed as a means of quantifying the concentration of starch (Tavers *et al*. 2002).

While starch, soluble solids and acid contents are often related to maturity, less emphasis is placed on protein or amino acid changes as they relate to maturity. Changes in both total and individual free amino acids were detected in muscadine grapes during maturation (Lamikanra and Kassa 1999). In limes, a greater concentration of a soluble protein was observed in yellow peel than in mature green peel, but since peel color offers a practical way of differentiating among maturity stages, a color index chart was developed for maturity stages 1-4 (from mature green to full-yellow) (Win *et al*. 2006). Peel (or ground) color has proven a very useful maturity index for many fruits, but other parts of the fruit also change their color as the fruit matures. Such is the case of apple seeds, which in combination with starch index can render useful information on fruit maturity (Lau and Lane 1998).

Texture is another feature that lends itself as a maturity index. Instrumental assessment of texture has evolved greatly during the decade. Time-resolved spectroscopy is a very powerful indicator of maturity which can provide information on the chemical composition of the commodity (absorption coefficient) as well as its texture (transport scattering coefficient) (Zerbini 2006).

The determination of maturity indices depends on whether the commodity will be consumed immediately after harvest or if it will undergo storage. If the commodity will be stored, the process of maturity index determination must include a storage and/or transportation period. In the case of apples, different starch index recommendations are provided depending on the storage method (regular or controlled atmosphere) and duration (Drake and Kupferman 2000). The interaction between maturity and duration of storage was also studied for bananas, where "days after fruit set" was found to be a good maturity index (Kudachikar *et al*. 2004). For kiwifruit, it was reported that "days after full bloom" along with firmness, soluble solids and sugars (in combination), were the ideal maturity index for fruit that were to undergo storage (Rana 2003).

HORTICULTURAL MATURITY DECISION END-POINTS

As depicted in **Fig. 1**, the process of selecting a maturity index relies on defining a decision end-point, which is a measure to judge whether a commodity is suitable for its intended use. For commodities which are meant to be used as food, the most adequate approach to determine if it is suitable for consumption is to conduct sensory evaluation. Some researchers have put aside this methodology and have focused on a trait of the commodity judged to have value in ascertaining its overall quality (soluble solids: titratable acidity, etc.). This can present a problem since quality is the result of many factors and the interactions among them. Sensory evaluation, on the other hand, can focus on the many aspects that define the quality of a commodity, such as its sensory "on-" and off-notes. In cantaloupe, for instance, flavor and aroma are the most valid indicators of quality. Maturity at harvest has an impact on these two aspects and panelists were able to discern between fruit harvested at ¼ slip over fruit harvested at ½ slip or higher (Beaulieu *et al*. 2004). Furthermore, other quality aspects which are not easily measured instrumentally such as "surface wetness" and "moisture release" were also lower when fruit were harvested at ¼ slip (Beaulieu *et al*. 2005). When many sensory attributes are measured as an end-point, results can be consolidated using a multivariate procedure. Such is the case in peaches, where three textural notes (hardness, rubberiness and juiciness) and six flavor notes (sweetness, sourness, bitterness, green, peachy and overripe character) were consolidated using Principal Component Analysis. A number of possible maturity indices were then correlated with the Principal Components to identify a suitable maturity index (Brovelli *et al*. 1998). Affective sensory evaluation is ultimately the best end-point measurement for commodities used as food. Jha *et al*. (2007) modeled the evolution of color as function of mango fruit maturity. In the end, fruit were judged by panelists who determined whether fruit of each maturity stage was either acceptable or unacceptable.

Since plant maturity dictates phytochemical composition, it is important that in bioactive plants maturity indices address nutraceutical considerations. In cases where specific phytochemicals have been linked to the function of a plant, the end-point will be given by the levels of the phytochemical in question. In a maturity study of broccoli, it was found that a significant correlation existed between the head's height, diameter and mass and the concentration of sulphoraphane in this organ (Omary *et al*. 2003). In alfalfa, it was reported that the concentration of health-promoting phytochemicals varied significantly with maturity, with the concentration of individual phytoestrogens showing a 15-fold change depending on maturity stage (Seguin *et al*. 2004). In most cases, however, because of a complex interaction among active principles within a plant, it is difficult to determine the effect of stage of development of a plant on its biological performance. Howard *et al*. (2000) reported that an interaction among flavonoids, caffeic and ascorbic acid was observed in the resulting antioxidant activity of pepper cultivars (*Capsicum* spp.)

Human gene expression can be a powerful tool to determine how a plant's ontogeny can affect its performance at the genetic level. In a maturity study of *Echinacea purpurea*, three phenological stages (1-vegetative, 2-bud and 3-erect ligules) of the herb were compared for their immune stimulatory effects on THP-1 monocyte/macrophage cell line. The levels of macrophage and monocyte-derived cytokines, including tumour necrosis factor alpha, interferon gamma, interleukin (IL)-1α, IL-1 β, IL-6, IL-10 as well as chemokines including Macrophage inflammatory protein-1 (MIP-1), and IL-8 were measured at the transcription level. When the three maturity stages were compared for their immune stimulatory effects, stage one material showed the most potent induction activity, especially on cytokines Interferon-gamma and Tumor necrosis factor alpha (Brovelli *et al*. 2005). For *Echinacea*, a plant with as many as seven biologically active phytochemicals, this approach allowed a more precise distinction of "functional stages" than phytochemical markers would have allowed.

CONCLUSIONS

In the process of selecting an appropriate maturity index it is important to bear in mind the intended use of the commodity, whether it is to be consumed fresh or processed, or if it is to be used for its nutraceutical properties. Once the intended use and the postharvest handling scheme (storage conditions, storage duration, etc.) have been defined, an appropriate model, i.e., a decision end-point, needs to be chosen to judge the quality of the commodity after having undergone the selected postharvest scheme. The decision end-point can range from sensory evaluation, to phytochemical assays, to human cellular or sub-cellular systems. It is apparent that the selection of a good maturity index is based on its good correlation with the decision end-point and *not* on its progressive change with time.

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