2007 vol. 66, 5-10
DOI: 10.2478/v10032-007-0001-0

SIMILARITIES BETWEEN QUALITY AND HEALTH PROMOTING COMPOUNDS AS A RESULT TO STRESS

L.M.M. TIJSKENS[1,2], M. SIMČIČ[3], R.E. SCHOUTEN[1]
[1]Horticultural Production Chains group, Wageningen UR, Wageningen, the Netherlands
[2]Agrotechnology & Food Innovations, Wageningen UR, Wageningen, the Netherlands
[3]Biotechnical Faculty, University of Ljubljana, Slovenia

Summary

Antioxidants are produce by plants as a defence mechanism against stress. It is not unlikely that quality related properties are related to that stress induced production system (secondary metabolites). Based on purely theoretical considerations and on scarce information from literature and experts, a highly speculative model was developed to investigate the possible importance of stress levels on the production of health promoting compounds and quality related properties. Simulations with that model, using completely arbitrary parameter values showed that a relation exist between applied stress and production of these beneficiary compounds.

key words: modelling, antioxidants, theoretical considerations

INTRODUCTION

Man can get stressed by any cause. And show a variety of responses as a result of that. For plants, the situation is not different. Stress can be induced to plants by a plethora of reasons, either too high or to low: e.g. temperature, light, water, fertilizers, salinity. And the responses are equally as many. Most of the time, the plant grows slower and product mass will consequently be lower.

Certain types of stress (i.e. suboptimal growing conditions) during the growth of plants (fruit and vegetable) cause an increased production of health promoting compounds (e.g. antioxidants). This can be considered as a normal response In terms of plant defence to detrimental stress induced reactions (Awad 2001, Simčič 2001). What is not so frequently considered normal as a response to stress is an increase in eating quality (taste, aroma). Nevertheless, it has been observed (Mulholland *et al*. 2002, Galindo *et al*. 2004) that stress (e.g. fertilisation, light, temperature, drought) produces a higher quality (taste aroma) in fruits and vegetables. Apparently the balance in the producing system gets somewhat disturbed, resulting in more sugar production out of the daily photo-assimilates.

Corresponding author:
e-mail: Pol.Tijskens@wur.nl

Not too much numerical data are available to analyse this similarity further. The reason for that is that growers are not too much concerned with producing quality or health promoting compounds, but more with mass and yield.

Quality or health promoting compounds are advantageous product properties only at the table of consumers. When both items will be considered important, growers will have to take these aspects into consideration. Some project proposals have been submitted to investigate the effect of stress on quality or health promoting compounds, but mostly in vain. The pressure from the consumer side is still not strong enough to convince growers and retailers of the advantages. Recently an EU Strep project started (IRRIQUAL) that could, as a side track, provide some information on this relation between quality and stress. Over the last decades the conditions of growth to produce the highest mass and dry matter have been optimised. But what has been left out of the optimisation criteria are the resulting properties in fruit and vegetables. Consumers more and more request their daily products to be of high quality, with a good appearance and of high nutritional and health value (Berna *et al*. 2005). During the postharvest trajectory quality will generally not increase and can only be maintained as good as possible. Therefore, a new type of optimisation of the production process has to be considered, and the criteria of the optimisation have to be extended to cover also these aspects of our daily food. Not too much is known about the exact mechanisms and processes that occur in growing produce. Some possibilities have been indicated by Tijskens & van Kooten (2006), putting the emphasis on the enzyme system involved in growing and maintaining quality.

Of course the exact mechanism will depend on the plant species, the type of stress, either constant or variable, and the remaining conditions during growth. Many questions still remain to be solved. E.g., is it beneficiary to apply variation in stress, like it occurs in uncontrolled growth in nature? Do different types of stress add up in their response? Or are they counterproductive? Some factors have been studied (e.g. salinity: Mulholland *et al*. 2002, water issues: Galindo *et al*. 2004, antioxidants: Awad 2001). What comes out of these studies is that controlled stress can cause an increase in internal quality like taste, flavour, sweetness etc. Also the so-called health promoting compounds like antioxidants (Simčič *et al*. 2001, Lana & Tijskens 2006) and glucosinolates (Dekker *et al*. 2000, Verkerk *et al*. 2001) are produced to a higher level as a response to stress of all kind. Too much stress will of course be detrimental to the product, inducing a very rapid decay. But even then, removal of the (too high) stress can have a beneficiary action, as was indicated by Veltman *et al*. (1999) for pears at suboptimal CA storage upon restoring optimal conditions.

In this paper, some theoretical examples will be worked out and models that deal with stress induced production will be presented to show some possible relations and similarities between quality or health promoting compounds as a response to stress.

PREMISES AND MODELLING

To better understand the functioning of the added production of quality and health promoting compounds, it would be worthwhile to investigate the possibilities of modelling this phenomenon at a generic level. That plants do produce more antioxidants in time of free radicals producing stress is not strange since antioxidants can be considered as life sustaining compounds. The relation with quality is somewhat more obscure, but nevertheless it can be assumed that the compounds we, humans, do perceive as internal quality of horticultural products are produce by the plant as part of their defence mechanism.

On purely theoretical grounds and completely speculative, a model was constructed to get a feeling of the importance and effects of stress on the defence mechanism in plants. To limit this vast area, attention was solely devoted to anti-oxidants and free radicals (Tijskens *et al*. 1994). The first reaction in (Eq. 1) represents the production of anti-oxidant activity (AA) out of the constant daily supply of photoassimilates under action of an enzyme (E). The second reaction describes the additional production of antioxidants under the action of stress (S). The third reaction represent the free radicals (R), produced by all reaction in living material. The next reaction represents the always present scavenging of free radical by anti-oxidants. The fifth reaction is the damage (dam) that free radical inflict upon the product, producing stress. The last two reactions are even more speculative and represent disappearance of anti-oxidants by damage already present, and the damage repair. The whole mechanism can thus be represented as:

$$E \xrightarrow{ka} AA + E$$

$$S + E \xrightarrow{ks} AA + E$$

$$\xrightarrow{kpr} R$$

$$R + AA \xrightarrow{ksc} scavenging \qquad \text{Eq. 1}$$

$$R \xrightarrow{kdam} S + dam$$

$$AA + dam \xrightarrow{kdamA} dam$$

$$dam \xrightarrow{kr} repair$$

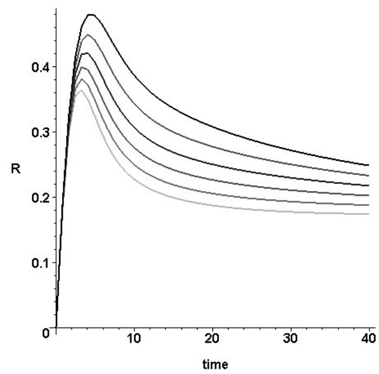
Based on the fundamental laws of chemical kinetics, the set of differential equations representing this complex mechanism in mathematical terms can be deduced (Eq. 2).

$$\frac{dAA}{dt} = ka \cdot E + ks \cdot E \cdot S + ksc \cdot AA \cdot R - kdamA \cdot AA \cdot dam$$
$$\frac{dE}{dt} = 0$$
$$\frac{dR}{dt} = kpr - ksc \cdot AA \cdot R - kdam \cdot R \qquad \text{Eq. 2}$$
$$\frac{dS}{dt} = -ks \cdot E \cdot S + kdam \cdot R$$
$$\frac{ddam}{dt} = kdam \cdot R - kr \cdot dam$$

Of course, this complex set of differential equations can not be solved for an analytical solution. Numerical integration of the system of differential equations as shown in Eq 2 has to be used for studying its behaviour. In Table 1 the values used in simulation are shown. Of course all values (including time) are completely arbitrary. Simulations are merely indicative of the general behaviour. In Fig. 1 the effect of increasing stress (from 0 to 5) on the production of antioxidants is shown. The increasing stress not only increases production of antioxidants but does also slightly change the shape of the curve.

Table 1. Input values for simulation using Eq. 2

Parameter	Value
A0	0.01
S0	2
E0	0.5
R0	0
dam0	0
Ka	0.9
Ks	0.2
Kpr	0.25
Ksc	0.2
Kdam	0.2
kdamA	0.25
Kr	0.2



Since the active enzyme system is so important in the whole mechanism, the effect of increasing levels of enzymes was simulated. The same input values were use (Table 1), with enzyme levels increasing from 0.1 to 1. In Fig. 2 the results are shown. Clearly an increasing enzyme level exhibits a much larger effect than stress (in this combination of input values).

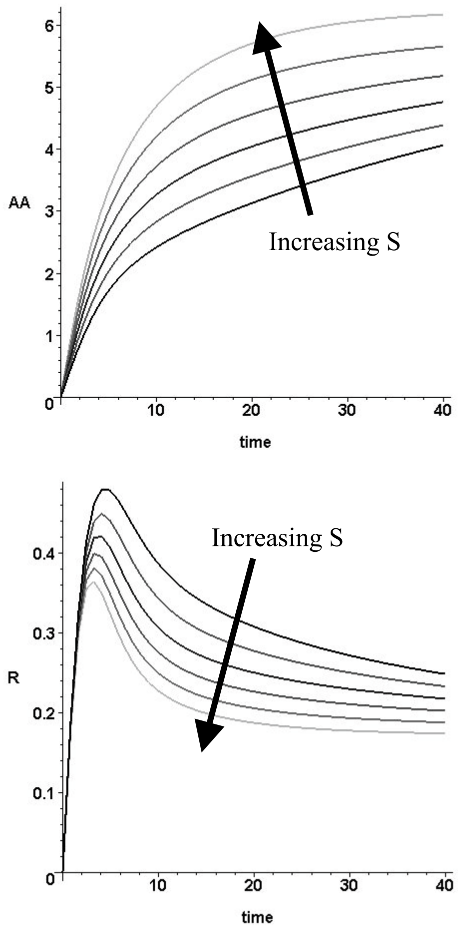


Fig. 1. Change in anti-oxidant levels (top) and free radicals (bottom) as a function of time for increasing stress levels

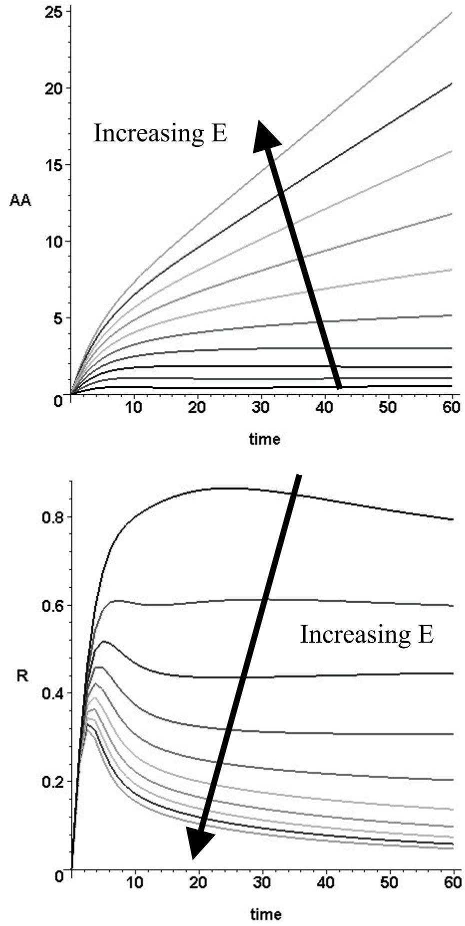


Fig. 2. Change in anti-oxidant levels (top) and free radicals (bottom) as a function of time for increasing enzyme levels

CONCLUSIONS

Although no firm conclusions can be drawn upon this highly speculative model (both on mechanism as on parameter values), the simulations do make clear that beneficiary effects of controlled stress can be large. And they do make clear that benefits can be expected for all concerned, growers as well as consumers and nutritionists, from this type of research. In other words, dedicated experiments along these lines of thinking can be expected to be successful.

Acknowledgement
The financial support of the EU by means of a grant for a short term scientific mission of COST 924 is gratefully acknowledged.

REFERENCES

Awad M.A. 2001. The apple skin: colourful healthiness. Developmental and environmental regulation of flavonoids and chlorogenic acid in apples. PhD thesis, Wageningen University, NL.

Berna A.Z., Lammertyn J., Buysens S., Di Natale C., Nicolaï B.M. 2005. Mapping consumer liking of tomatoes with fast aroma profiling techniques. Postharvest Biol. Technol. 38: 115-127.

Dekker M., Verkerk R., Jongen W.M.F. 2000. Predictive modelling of health aspects in the food production chain: a case study on glucosinolates in cabbage. Trends Food Sci. Technol. 11, Issues 4-5, 5 April 2000: 174-181.

Galindo F.G., Herppich W., Gekas V., Sjöholm I. 2004. Factors affecting quality and postharvest properties of vegetables: Integration of water relations and metabolism. Critical Rev. Food Sci. Nutr. 44, Issue 3: 139-154.

Lana M.M., Tijskens L.M.M. 2006. Effects of Cutting and Maturity on Antioxidant Activity of Fresh-Cut Tomatoes. Food Chem. 97/2: 203-211.

Mulholland B.J., Fussell M., Edmondson R.N., Taylor A.J., Basham J., McFee J.M.T., Parsons N. 2002. The effect of split-root salinity on tomato leaf expansion, fruit yield and quality. J. Hort. Sci. Biotechnol. 77**:** 509-519.

Simčič M., Hribar J., Brodnik U. 2001. Compartmentisation and nutritional value of polyphenols and ascorbic acid in apples. In: Molecular and genetic interactions involving phytochemicals. (Kreft I., Škrabanja V. eds). Proceed. European scientific symposium in Gozd Martuljek. pp: 203-208, Biotehniška fakulteta, Ljubljana, SI.

Tijskens L.M.M., van Kooten O., Otma E.C. 1994. Photosystem 2 quantum yield as a measure of radical scavengers in chilling injury in cucumber fruits and bell peppers. Planta, 194: 478-486.

Tijskens L.M.M., van Kooten O. 2006. Theoretical considerations on generic modelling of harvest maturity, enzymes status and quality behaviour. Int. J. Postharvest Technol. Innovation 1: 106-120.

Rezaei Nejad A., van Meeteren U. 2005. Stomatal response characteristics of Tradescantia virginiana grown at high relative air humidity. Physiol. Plant. 125: 324-332.

Veltman R.H., Sanders M.G., Persijn S.T., Peppelenbos H.W., Oosterhaven J. 1999. Decreased absorbic acid levels and brown core development in pears (*Pyrus communis* L. cv. 'Conference'). Physiol. Plant. 107: 39-45.

Verkerk R., Dekker M., Jongen W.M.F. 2001. Post-harvest increase of indolyl glucosinolates in response to chopping and storage of Brassica vegetables. J. Sci. Food Agric. 81: 953-958.

ZALEŻNOŚCI POMIĘDZY JAKOŚCIĄ A PROZDROWOTNYMI SKŁADNIKAMI JAKO WYNIK STRESU

Streszczenie

Antyutleniacze są produkowane przez rośliny na skutek uruchamiania mechanizmu obronnego przeciwko stresowi. Jest niewykluczone, że cechy odpowiedzialne za jakość są związane z tym mechanizmem, indukowanym przez stres. Opierając się na czysto teoretycznych rozważaniach i na nielicznych doniesieniach z literatury, stworzono wysoce spekulatywny model w celu sprawdzenia możliwość wpływu różnych poziomów stresu na produkcję prozdrowotnych składników przez rośliny. Symulacje modelowe wskazują, że istnieje zależność pomiędzy zadanym stresem a produkcją korzystnych dla zdrowia człowieka składników.