Breeding Potato with High Antioxidant Values

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Introduction

The potato needs no introduction to most Americans. It is a common food, eaten as a snack or adjacent to a main course in a meal. Most people think of it as a highly palatable food that accompanies other foods in an excellent fashion. It is not, however, thought of as a health food. This is despite the fact that it has a high quality protein and is loaded with vitamin C. It is not widely known that potato has the potential of providing high levels of antioxidant in the form of natural red and purple anthocyanins. Although red and purple fleshed potatoes are thought of more as a novelty food at the present time, their high antioxidant values provide a good justification to make them a common item in our diet. This paper will describe some aspects of breeding potatoes with solidly red and purple flesh.

Antioxidants in foods

An antioxidant is any substance that, when present at low concentrations compared to those of an oxidizable substrate, significantly delays or prevents oxidation of substrates. Research has shown that people with diets including foods that are high in antioxidants have lower rates of certain cancers, and less heart disease (Knekt et al., 1996; Hertog et al., 1993). The human body maintains a pool of antioxidants, which can be augmented by dietary choices. People in oxidative stress, such as smokers, suffer depletion of naturally present antioxidants, such as vitamin E, but depleted vitamin E can be restored to some degree by consumption of antioxidants. Oxidative reactions start with the formation of a reactive oxidative species (ROS°). ROS°'s start chain reactions that result in the successive production of ROS°'s.

$$ROS^{\circ} + A\text{-red} \longrightarrow ROSH + A\text{-ox}^{\circ}$$

The ROS°'s at each stage in the chain are highly reactive compounds that can unleash undesirable processes such as the polymerization of low density lipoproteins associated with atherosclerotic lesion formation in vascular tissue (Halliwell, 1997). Oxidative chains proceed unimpeded until an antioxidant stops the reaction.

An antioxidant in its reduced state donates a proton to the ROS° and the antioxidant is itself oxidized. An effective antioxidant will, however, buffer the energetic transfer and instead of continuing the oxidative chain will quench the reaction as depicted in figure 1 where the oxidative chain is likened to the successive toppling of dominoes which can only be terminated by an antioxidant (represented by the dove).

Breeding behavior

The presence and absence of pigment in the skin and tuber flesh are determined by the action of several single genes. A listing of these is shown in Table 1.

Table 1. Single genes controlling pigmentation in potato tubers

Gene symbol	Effect	Inheritance
D/d	Red pigment in skin	Dominant monogenic
P/p	Purple pigment in skin	Dominant monogenic
Pf/pf	Pigment of all types in flesh	Dominant monogenic
I/i	Pigment expressor	Dominant monogenic

The *I/i* gene has the interesting effect that parents having the *iiii* genotype will lack pigmentation in the tubers, but may give rise to pigmented progeny (if they harbor *P* or *D*) if the dominant form, *I*, is present in the other parent.

Although presence of pigment in the tubers is controlled by a single gene, *Pf*, the extent of pigmentation is apparently under polygenic control. Thus pigmentation can vary from flecks, rays, or rings to solidly colored flesh. The intensity of the pigment and thus the concentration of the anthocyanin may vary considerably, and is similarly under the control of polygenes.

In figure 2 the breeding behavior of several crosses is shown. In panel A, a red flesh x white flesh cross-yielded only 3% of the progeny with completely red flesh. In contrast, a red flesh x red flesh cross-produced 21 percent of the progeny with completely red flesh (Panel B). Interestingly, in both crosses, the proportion with partially red flesh was the same, 43%. The cross-depicted in panel C is red flesh x white flesh type. It demonstrates the surprising effects of the *I* gene. The parent A77715-6 must have been homozygous recessive (*iiii*) at the *I* locus while also containing the *P* gene for purple color. The *P* gene was unexpressed due to the absence of the dominant allele of the *I* locus. Upon crossing, the *D* and *I* genes (contributed by the N40-2 parent) were present and segregating in the progeny as well as the *P* gene (contributed by the A77715-6 parent where it was silent in the presence of *iiii*). The result was a complex array of partial and completely red and purple flesh colors.

A summary of the results of 15 crosses is shown in panel D. Overall, red flesh x red flesh crosses yielded approximately three times as many completely red progeny as the red flesh x white flesh crosses (14.5%versus 5.8%).

Anthocyanin content and antioxidant values

The pigments in the potato flesh were extracted and analyzed with a spectrophotometer to determine the concentration. The range of concentrations is shown in figure 3. In previous studies, NDOP5847-1 was reported to have the highest reported anthocyanin value (Rodriguez-Saona et al., 1998). It is noteworthy in this study that a number of clones far surpassed this level by two- to three-fold. This indicates that the genetic potential for obtaining higher concentrations of anthocyanin is fairly large.

A group of clones were analyzed for the antioxidant potential. Two measures were used, Oxygen Radical Absorption Capacity (ORAC) and Ferric Reducing Ability (FRAP). Although ORAC and FRAP utilize different chemical reactions to measure antioxidant potential, they were very strongly correlated with each other. The red and purple potatoes show much higher antioxidant values than orange and white flesh potatoes (Fig. 4). Interestingly, the purple flesh potatoes have comparable antioxidant values despite having lower anthocyanin contents than the red flesh potatoes. This might be due to a more potent antioxidant property associated with the principal purple pigment, acylated glycosides of petunidin. A comparison of the results in this study to other vegetables reputed to provide high antioxidant properties is shown in table 2.

Table 2. Comparison of antioxidant values of common foods and pigmented flesh potato to white flesh potato (Adapated from Cao et al., 1996)

Food item	Antioxidant Value (Percent of white potato)
Garlic	625
Kale	571
Spinach	406
Purple flesh potato	330
Brussels sprouts	280
Red flesh potato	270

Red and purple flesh potatoes can be placed in the same category as Brussels sprouts in terms of antioxidant value. This constitutes a paradigm shift in the valuation of the nutritional value of potato. Pigmented potato should now be placed in the functional food category.

Concluding remarks

The development of potato with high antioxidant values provides several opportunities for the potato industry. First, it should be possible to produce snack foods that have high antioxidant potential. The same rationale that advocates that green, orange, red vegetables or leafy vegetables be increased in the diet can also be applied to recommending increased consumption of red and purple flesh potatoes. Second, the pigments in the potato can be developed as natural colorants. Lastly, the anthocyanin pigments can be marketed as nutritional supplements (nutraceuticals). The purified and crude extracts of bilberry (*Vaccinium myrtillus*) are now sold as an aid to eye health based on evidence that the anthocyanins retard macular degeneration. This product is particularly popular in Japan. The development of similar products, based on pigmented potato, simply awaits the appropriate entrepreneurial approach.

References

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$$ROS^{\bullet} + X_1H \rightarrow ROSH + X_1^{\bullet}$$

$$X^{\bullet} + X_2H \longrightarrow XH + X_2^{\bullet}$$

$$X_2^{\bullet} + X_3H \longrightarrow X_2H + X_3^{\bullet}$$

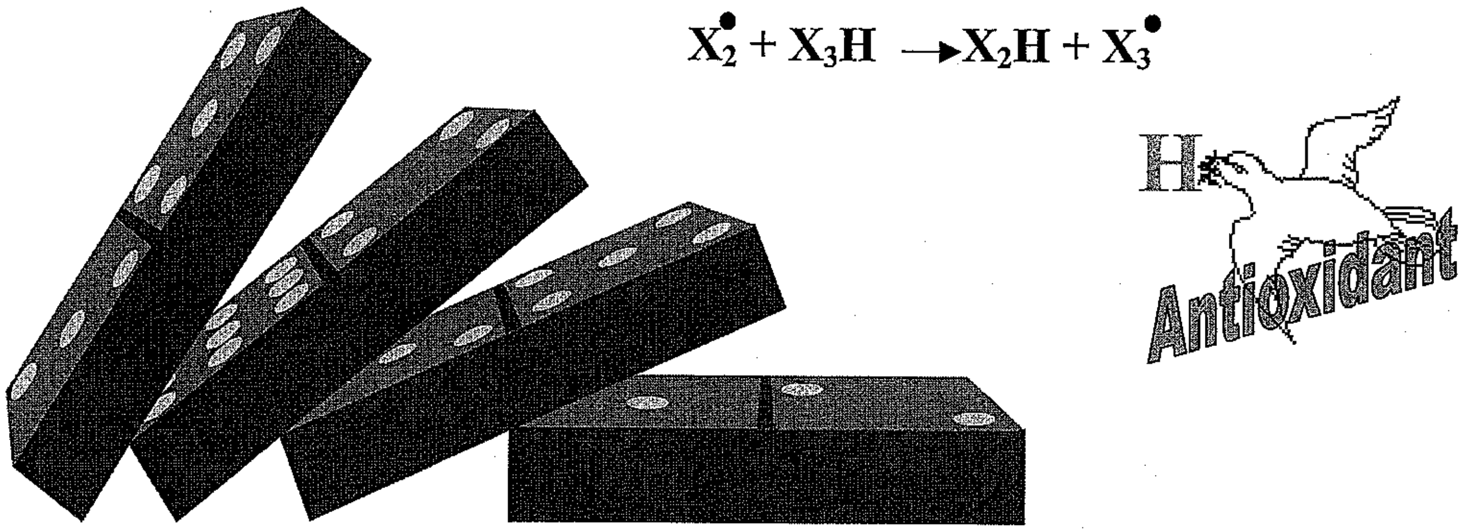

Fig. 1. An oxidative chain is likened to the toppling of a series of dominoes. The reactive oxidative species (ROS) status is passed off from one molecule to another (X_1, X_2, and X_3) until the antioxidant, represented by a dove with a proton in its mouth, quenches the reaction, thus stopping it.

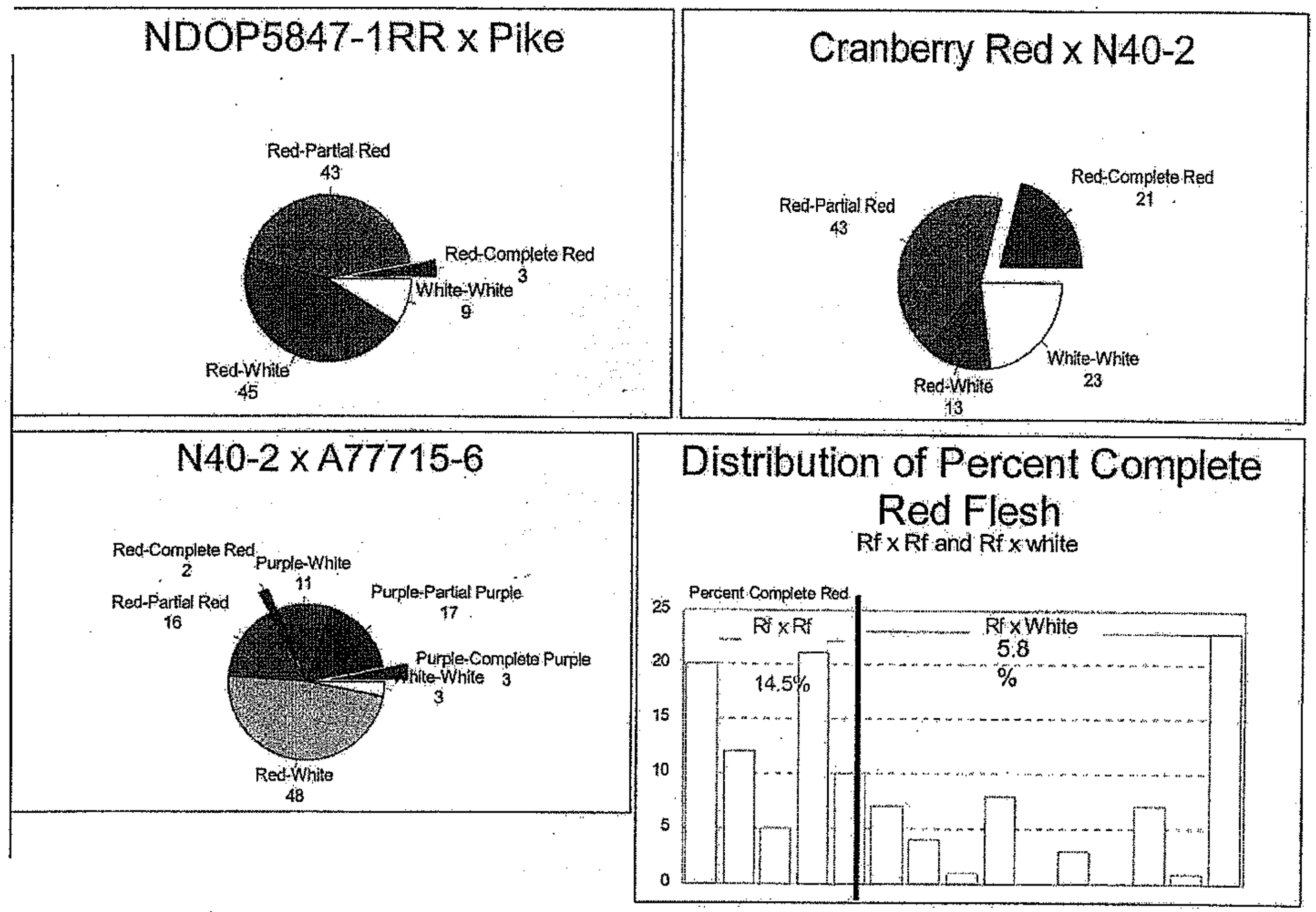

Fig. 2. Segregation patterns of solidly pigmented crosses. A) A red flesh x white flesh cross. B) A red flesh x red flesh cross. Note the much higher percent of "red skin completely red flesh" progeny. C. A red flesh x white cross that had the *P* gene together with pigment expressor gene, *I*. The purple pigment reappeared in the progeny when in the presence of the *I* allele. D) The mean percentage of pigmented flesh progeny was 14.5% for red flesh x red flesh crosses and only 5.8 % in red flesh x white flesh crosses.

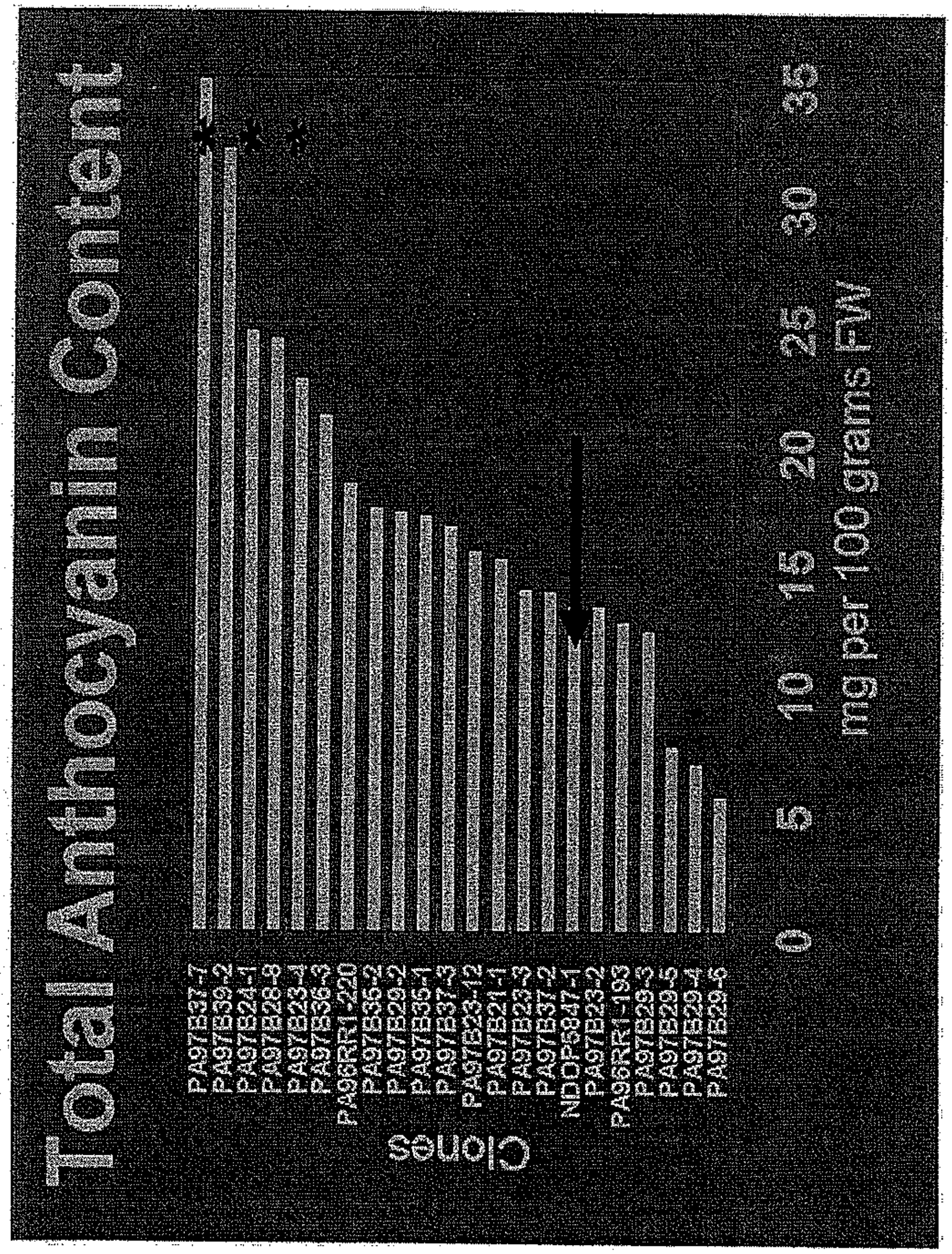

Fig. 3. Total anthocyanin contents for a series of red and purple flesh clones. The range of contents is quite broad. The previous highest clone identified in initial studies (indicated by arrow) was far surpassed by more recent selections (indicated by asterisks).

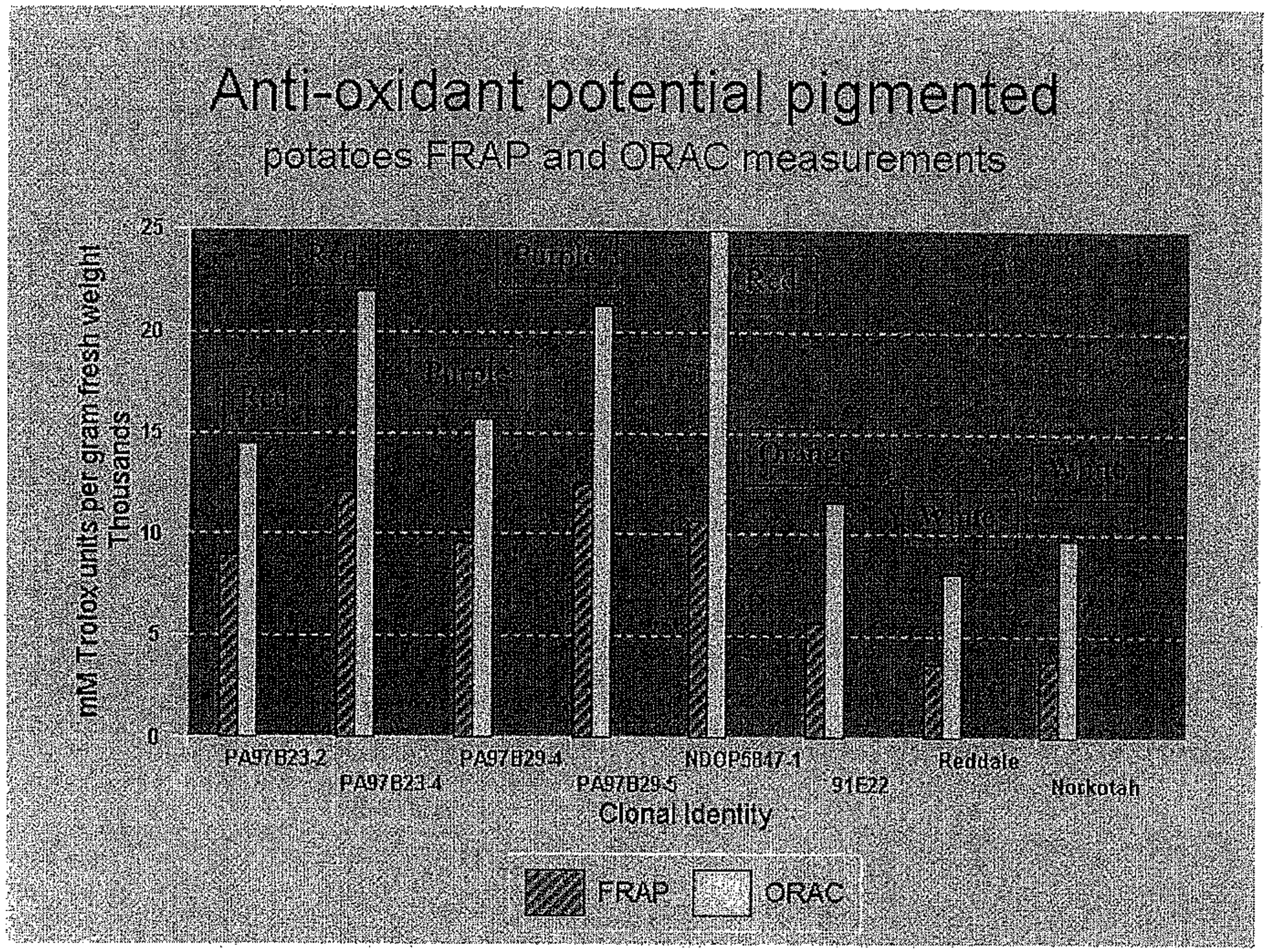

Fig. 4. Antioxidant potential based on two measurements, Oxidative Radical Absorption Capacity (ORAC) and Ferrous Radical/Absorption Potential (FRAP). The red and purple flesh potatoes show a two to three-fold increase in antioxidative potential compared to orange- or white-fleshed potato.