Results in table beet breeding (Review)

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Origin and types of table beet root

The table beet root belongs to the family *Chenopodiaceae* in the species *Beta vulgaris L.*, together with sugar beet (*B. vulgaris provar. altissima*), fodder beet (*B. vulgaris convar. crassa provar. altissima*) and chard (*B. vulgaris convar. cicla*). Every subspecies has 9 chromosomes and they intercross easily. Beets are wind pollinated, so, the isolation distance (3000 m) must be kept strictly.

The first cultivated form of beet root came from the wild species *Beta maritima* of which only the leaves were consumed.

The beet root cultivated today (*Beta vulgaris L. ssp. esculenta Gurke var. rubra L.*) was developed from the Sicilian beet in the 16. century. In those days the yellow type with higher sugar content was preferred while today varieties of red colour are found in production. As specialities some varieties of white and yellow flesh, respectively, are also cultivated.

According to root shape varieties can be ranged into 3 types:

- flat – for early fresh consumption
- round – for early fresh consumption (baby beet root in bunches) as main crop for canning
- cylindric – processing industry, sliced products

Quality indices and processing

Beet root quality is greatly determined by the inner colour of the root and its uniformity (lack of white rings).

Other important parameters are the sugar and solids contents which take part in flavour evolution. The fineness of the flesh, the fibre content, the smoothness and corkyness of the rind and the fineness of the taproot must also be considered.

Yet, it is the pigment content which is mostly dealt with as the most important factor in the determination of quality because it is an excellent source to produce natural food colouring agents.

The colour of the beet root is determined by two main pigment groups – the orange betaxathine and the red betacyanins – found in cell vacuoles. They are called betalaines collectively.

The betacyanin is a mixture of two glycoside and their aglycons (*Fig. 1*).

The red pigment is found in several components the ratio of which differs in the different varieties (*Table 1*) and determines pigment composition and stability (*Takácsné Hájos*, 1999).

The composition of yellow pigments was studied in the yellow beet root (*Beta vulgaris var. lutea*). 8 components were found with vulgaxanthin I and II as the most important ones (*Savolainen & Kuusi*, 1978).

Table 1 Red pigment content (mg/100g) and composition in the table beet root varieties, Szarvas, 1998. (after Takácsné Hájos, 1999.)

Components Variety	Betanin	Isobetanin	Betanidin	Isobetanidin	Red pigments total
BONEL	50.03	26.62	4.20	0.96	81.81
NERO	40.29	13.10	2.92	1.12	57.43
FAVORIT	49.53	24.04	4.61	2.10	80.24
RUBIN	46.26	25.16	6.63	2.96	81.01
DETROIT	43.35	21.29	5.13	1.16	70.93
The mean of varieties	45.89	22.03	4.70	1.66	74.28
LSD (0.05)	4.31	1.91	0.52	0.34	6.62

Today industry prefers the red type used to produce powder and concentrates as food colouring agents.

Accordingly-breeding mainly aims at increasing the pigment quantity and modifying quality indices which promote pigment extraction.

For beet salad products raw material of high pigment and water soluble solids concentration is needed.

Beet root solids are generally known to consist mainly of sugars which have an important part in the evolution of flavour.

The total sugar content (3.5–8.8%) consists of sucrose in 92–95% and only the remaining part is reducing sugar. This

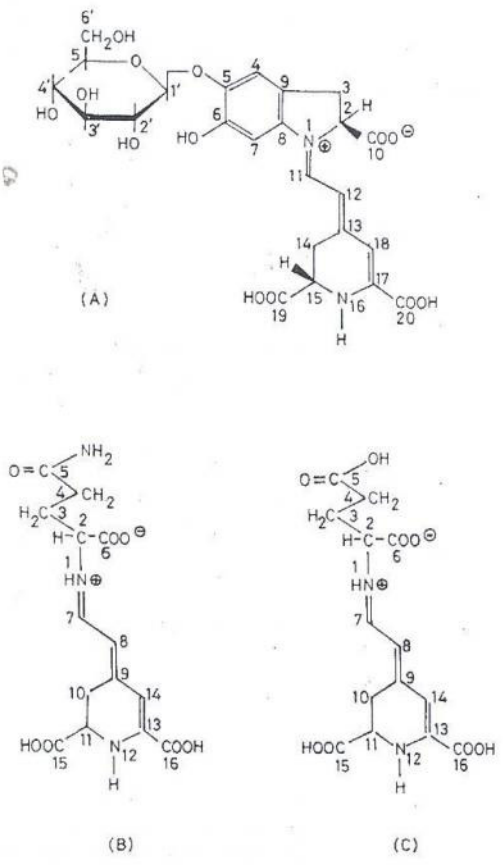

Figure 1 A betanin, B vulgaxanthine I, C vulgaxanthine II

explains why raw materials of little sugar content have poor processing quality.

For production of colouring agents – powder or concentrate – low solids content is desired because during processing heat caramelizes the higher sugar content. This process is a disturbing factor in making concentrates, too. The production of colouring agents requires raw material of low sugar content, on the contrary, salad products require varieties of high pigment and water soluble solids (sugar) content.

Watson & Gabelman (1984) when developing beet root varieties corresponding to these requirements found significant general combining ability for sugar content in progenies from diallel crosses of inbred lines while the specific combining ability did not show any significant difference. Furthermore, the large positive phenotypic and genotipyc correlations between betacyanine and betaxanthine concentration suggest that selection for increasd levels of one pigment would result in increased levels of the other (*Table 2*).

Besides the pigment and solids contents there are numerous other factors which are to be considered, e.g. vitamin content. Folic acid (vitamin-B) is found in large proportion in leaf vegetables of dark green colour (cabbage, spinach, etc.). Compared with other vegetables large quantites of free and total folic acid was measured in the beet root, either raw or cooked (*Goddard & Matthews*, 1979). *Wang & Goldman* (1996) found considerable phenotypic difference among varieties. In their tests they established 1.84 heritability value for free folic acid (*Wang & Goldman*, 1997).

Table 2 Genotypic (r_g), phenotypic (r_p), and environmental (r_e) correlation among 4 traits, estimated from F1 data of a diallel cross. (after Watson & Gabelman, 1984)

Trait	Statistic	Trait: Betacyanine	Betaxanthine	Betacyanine/ Betaxanthine
Betaxanthine	r_g	0.87		
	r_p	0.79**		
	r_e	0.54**		
Betacyanine	r_g	-0.41	-0.91	
	r_p	-0.20*	-0.73**	
	r_e	0.22**	-0.58**	
Sucrose (%)	r_g	0.12	0.14	-0.29
	r_p	0.18	0.17	-0.09
	r_e	0.37**	0.27*	0.02

*;** Significance at the 5% and 1% level, respectively.

Genetic results

Keller (1936) outlined the base of pigment genetics in beet root. A dominant factor G is responsible for the evolution of yellow pigments while for the violet and red pigments a dominant factor R is responsible besides the factor G. Several alleles of them are known out of which he established the following dominance line:

$$G > G^r > g$$
$$R^l > R > r$$

The phenotypic appearance of pigment genotypes is presented in *Table 3*.

Table 3 Main colour genotypes in beet root

Genotypes	Leaf			Root (flesh and rind)
	blade	nervure	petiole	
$G^r R$	green	yellow	yellow	red
$G^r R^l$	green	slightly red colouring can occur	red striped	red
GR	red colouring can occur	red colouring can occur	dark violet red	vivid red (violet)

Accoording to *Wolyn & Gabelman* (1989) the gene R regulates the ratio and concentration of pigments in the root as well as the striped character of the leaves. They also established that the gene R is of complex structure and regulation and it has a regulative role in the biosynthesis of pigments. This process is influenced favourably by the higher light intensity during the growing period (*Weichman*, 1987) as also affirmed by the cell culture trials of *Gired & Zrid* (1986).

The inner colour of beet root is characterized by the betacyanin and betaxanthin ratio. *Wolyn & Gabelman* (1986,

1989) divided beet root varieties into 4 groups based on these qualities the development of which they attributed to the regulatory effect of different genotypes.

BC/BX ratio	phenotype	marking	genotype
0.020-0.061	low	L	R r
0.513-0.813	small	LR	R^r r
1.10-1.73	moderate	MR	R^r R^r
2.01-5.65	high	HR	R^r R^r or R^r R

In beet root breeding it was a great step forward when the genetic factor of self-incompatibility became known. The sf allele causing self-fertility introduced into beet root came from a sugar beet inbred line developed by *V. F. & H. Savitsky*. This allowed *W. H. Gabelman* to develop inbred beet root lines. The *x* and *z* alleles maintaining sterility were also introduced into beet root from sugar beet lines developed by *F. V. Owen.*

Mostly citoplasmic-genic male-sterility is used to develop hybrids. There are two kinds of citoplasms: N - normal or fertile and *S* - sterile. Sterility is transferred to progenies by the plasma *S* which needs a male-sterile genotype for realisation. There are, however, other *X* and a *Z* nucleus genes within the genom which, with the sterile plasma together, result in a complete male-sterility. Thus, to propagate the male-sterile strain *(Sxxzz)* there must also be a maintaining strain *(Nxxzz)* available to produce pollen.

As table beet root is a biennial plant breeding takes a long time. Due to the presence of allele *B* transferred from sugar beet the annual character can be made inheritable. Thus, plants sown in spring produce seed stalks by mid-August of the same year.

For this purpose individuals with *S xxsfsfBb* x *N--sf-bb* character were crossed which yielded annual progenies (Bb) in more than 50%. The selected sterile plants were then decapitated, vernalized and let bloom together with the maintaining line in a greenhouse (*Goldman*, 1996).

Considerable labour can be saved by using monogerm varieties, as they can easily be drilled and do not need thinning. Furthermore, germination and root development are more uniform (*Benjamin & Bell*, 1985).

Banga (1962) described the monogerm character as of monogenic (mm) inheritance. The allele m assuring the monogerm character was also transferred from sugar beet but it needed 10 generations of strict selection to recover the proper round type and red colour (*Goldman*, 1996). In recent years several monogerm and hybrid beet root varieties are marketed. The higher seed cost is compensated by the number of uniform roots, that is, by the higher marketable yield.

The genes favouring beet root breeding (male-sterility, monogerm character) were mostly introduced from sugar beet, its own gene stock was studied in much less extent. Of results of recent years the blotchy root colour, the fasciated flower stem and the apearance of dwarf mutants can be mentioned.

The presence of pigment deficiency (irregular spots with pigment deficiency) and white roots is a genetic alteration due to mutation. When crossing them with inbred individuals of normal colour *Watson & Goldman* (1997) found a recessive gene *(b1)* which caused that special phenotype.

In beet roots fasciated flower stems occur frequently. It is characterized by the excess growth of lateral buds instead of apical dominance. Similar symptoms are found in infections with *Rhodocossus fascians* (*Crespi* et al., 1992) and *Corinebacterium fascians* (*Murai* et al., 1980). In their infection trials *Crespi* et al. (1992) stated that the introduction of a plasmid into the citokinin synthetase gene was the cause of the deformation.

Leyser & Furner (1992) found that genetic degeneration could cause similar thickening of the meristem.

Goldman (1998) designated this gene as *ffs* in beet root and supposed a lack of maternal effect in inheritance.

Goldman & Watson (1992) dealt with the inheritance of a dwarfing gene. Their studies showed it to be of monogenic *(dw)* character which modifies the gibberellin biosynthesis of the plant.

Breeding methods in beet root

At the beginning of beet root breeding mass selection was the most frequent method (*Banga*, 1962) mostly used to maintain the population performance of uniform types. It also proved adequate to develop polygenic resistance.

Family breeding was widely used to improve root quality. The method was later modified by the vegetative propagation of mother plants. It can also be used to produce breeding base material for different purposes.

The pigment heritability value of 0.81 - 0.82 (*Wolyn*, 1986) also indicates the usability of selection to improve this quantitative character.

Wolyn & Gabelman (1990) used successfully a 3-cycle half-sib family selection method to develop beet root families of high pigment and low sugar contents and also of high pigment and high sugar contents. In their trials the selection index of pigment recovery per cycle was 21,2% and 29,1%, respectively, in the two different populations.

According to their trials the selection success for pigment concentration and water soluble solids contents depended on an adequate genetic variability and a favourable genetic correlation between the two characters.

Recurrent selection also proved favourable to improve pigment content but the parallel decrease of solids content did not prove realistic (*Goldman* et al., 1996) as in the biosynthesis of both the red and the yellow pigments glucose is an important component (*Fig.2*) and so the increase in pigment formation cannot be made independent of solids (sugar) accumulation.

It is well know that beet root is a self incompatible plant due to gametophytic causes, so, only mild forms of inbreed-

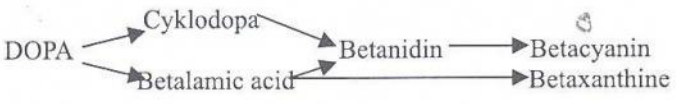

Figure 2 Betalain biosynthetic pathway proposed by Mabry,1980

ing can be used. This explains the utility of paired mating in this species to improve mostly quality parameters.

This method was used in our trials to improve the quality of the variety *Bordó (SU).* For this purpose some beet root families of high pigment content were developed in which, the average, 30–40% pigment improvement was obtained in the first and second generations. However, this process was accompanied by 10–16% yield reduction which reached more than 50% in the third generation. In this generation pigment content only improved slightly (*Takácsné Hájos*, 1993).

In the development of varieties, hybrid breeding is becoming more and more important. This can be explained by the superior quality and uniformity of the roots. In open pollinated varieties about 60% of the roots are marketable, in hybrids, however, the ratio is 70–75% (*Michalik* et al., 1985).

Gene banks and breeding base materials

A wide genetic base material is indispensable to satisfy modern variety requirements. Backcrosses with wild species are often needed. In this field gene pools and germplasm collections are of high importance. They possess breeding materials (even beet root lines) of numerous individual characters.

The Vavilov Institute of Plant protection, VIR, keeps the world's beet root collection in evidence including about 400 items (*Burenin*, 1994).

The collection of inbred sterile lines developed within Gabelman's breeding program is available to every beet root breeder and geneticist (*Goldman*, 1996). The publication of germplasm lists makes possible to continue the important research achieved at the University of Wisconsin, Madison in the field of table beet root breeding.

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