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# Assessment of breeding progress in sugar beet by testing old and new varieties under greenhouse and field conditions

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ABSTRACT

Breeding has led to a continuous increase of the performance of sugar beet varieties and thereby contributes to meet the global needs for food and biomass. This study aimed to analyze the extent of the breeding progress in sugar beet and to determine which parameters and traits were modified by breeding. In 2007 and 2008 sugar beet varieties registered between 1964 and 2003 were cultivated in field trials and in greenhouse experiments to exclude effects from changes in agronomic operations and climatic conditions. Differences in white sugar yield related to the reference variety registered in 1964 were regarded as breeding progress. The results showed an increase in the white sugar yield of 0.6–0.9% $a^{-1}$ from 1964 to 2003 due to breeding. This was achieved by an improved biomass partitioning (higher root to leaf ratio and higher sugar to marc ratio), better technical quality (decreased concentration of K, Na, and amino N combined as standard molasses loss) and enhanced assimilation (higher chlorophyll content, higher assimilation rates). No changes were observed in leaf development and cambium ring formation. A principle component analysis pointed out that breeding targets have shifted with time from “yield” to “biomass quality”. To continue the breeding progress in future it is essential to integrate multiple resistances and tolerances against biotic and abiotic stress.



## 1. 1 Introduction

An increase of the worldwide crop production is necessary to guarantee future food security (Foley et al., 2011). Two approaches are possible to achieve this target. The first one is the expansion of the arable area worldwide. Between 1985 and 2005, the croplands and pastures increased by 154 million hectares, or about 3% (Foley et al., 2011). This increase is obviously very small, and it is assumed that arable land will be of strictly limited availability (Miflin, 2000). The second approach is to improve the productivity of the given area by increasing the yield of agricultural crops through optimized cultivation or increasing yield potential of the crops. In several studies the yield increase of different major crops has been analyzed. For all crops a yield increase of 1–2% per year has been found between 1960 and 2005 (Foley et al., 2011; Ewert et al., 2005).

Different parameters can be used to describe the improved agricultural productivity. One parameter is the yield increase of a crop with time which is attributed to the progress in plant breeding, but also to changes in agronomy and environmental conditions, in particular of the climate (Evans and Fischer, 1999). Another parameter is the yield potential of a crop, which is defined as the yield of a cultivar when grown in environments to which it is adapted, with no limits of nutrients and water and an effective control of pests, diseases, weeds, lodging, and other stresses (Evans, 1993). Breeding progress usually results in an increase of the yield potential of a crop which can only be analyzed, when the performance of varieties with different years of registration is compared under the same environmental conditions.

A detailed analysis of the yield increase and the underlying causes has to be carried out separately for different crops. In variety trials, the yield increase of winter wheat in Chile was found to be 2.6% $a^{-1}$ between 1976 and 1998 (Matus et al., 2012). Shearman et al. (2005) determined a breeding progress of wheat varieties in the UK of 1.2% $a^{-1}$ between 1972 and 1995. In a meta-analysis Fischer and Edmeades (2010) determined an improvement of the yield potential of 0.3–0.6% $a^{-1}$ in wheat, 0.0–0.9% $a^{-1}$ in rice and 1.0% $a^{-1}$ in maize in different regions of the world.

Despite these successes there is some evidence that for several crops the yield increase, and the breeding progress as well, have slowed down in the last years (Matus et al., 2012; Brisson et al., 2010; Fischer, 2007). This indicates that a detailed analysis of the causes of breeding progress is essential to identify physiological factors limiting yield, and to develop new breeding targets for further progress in plant breeding.

The causes of breeding progress can differ in different crops. For wheat, the increased grain yield was attributed to the extension of the growth period, increases in radiation use efficiency and

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increasing sink strength (Miralles and Slafer, 2007; Reynolds et al., 2005; Richards, 2000), and furthermore, to an improved harvest index due to the shift of assimilates from the stem to the grains as a result of a reduction in plant height (Reynolds et al., 2009; Zhou et al., 2007). Varieties with shorter straw additionally have a higher yield stability as they are less susceptible to lodging and have a better use of N fertilizer (Brancourt-Hulmel et al., 2003). However, it is assumed that the alteration of the harvest index will be limited to about 0.5 due to decreasing stem stability and reduced light intercepting leaf area with increasing harvest indices (Miralles and Slafer, 2007; Austin, 1999). In maize, the breeding progress has been mainly attributed to improved stress tolerance such as drought stress (Bolanos and Edmeades, 1996; Tollenaar and Wu, 1999). However, breeding for high yielding maize varieties has led to a decrease in protein concentration, while starch concentration has increased (Duvick and Cassman, 1999) due to the negative correlation of both parameters in maize kernels (Doehlert and Lambert, 1991). Inversely correlated breeding targets may thus reduce the breeding progress in terms of yield, as described for several cereals (Simmonds, 1995).

In Germany, new varieties are only registered when they are proven to be better in their total value for cultivation and use than registered varieties (SaatG, 2006), so that a continuous breeding progress of agricultural crops can be achieved. So far, there are only few studies, in which the breeding progress of sugar beet has been analyzed. Generally, the white sugar yield is used to describe improvements in production and breeding as it combines yield and technical quality. In several studies, factors affecting the yield of sugar beet (Barocka et al., 1972; von Boguslawski and Schildbach, 1969; Fuchs et al., 2008; Märländer et al., 2003; Wolf and Märländer, 1994) and the production increase of sugar beet varieties over a long period of time have been investigated (Hoffmann and Märländer, 2002; Jaggard et al., 2012; Schuster, 1970). Jansen and Stibbe (2007) described an exponential yield increase of the varieties in official trials in Germany. However, the production increase is always higher than the breeding progress as additionally to the yield potential climate change and improved cultivation techniques are included.

A theoretical yield potential of 24 t white sugar per ha was estimated for sugar beet by Kenter et al. (2006) on basis of the maximum growth rates under different growing conditions for Germany and comparable agroclimatic regions. Koch (2006) investigated the genetic basis of the yield increase between 1966 and 2005 in an experimental approach, but included only varieties of one breeding company, so that the genetic basis was not representative. Scott and Jaggard (2000) calculated the breeding progress of sugar beet in a meta-analysis comparing the performance of different varieties relative to reference varieties registered between 1972 and 1982. They found a breeding progress of 0.9% $a^{-1}$. In addition to yield, the technical quality of sugar beet was analyzed with regard to breeding progress (Burba and Jansen, 2000; Jansen and Stibbe, 2007; Kenter and Hoffmann, 2009).

Breeding progress can result from an improvement of various physiological processes and parameters. Analysing physiological aspects, Loomis (1979) described an ideotype of sugar beet which is characterized by a larger initial storage root size and/or growth capacity, low maintenance respiration, selective turnover of enzymes, and a small celled root tissue. Consequently, breeding progress should therefore result in an improvement of any of these properties.

It is assumed that the breeding progress is mainly based on an increased root yield with little change in sugar concentration (Hoffmann, 2006). Furthermore, an increased harvest index and an improved early development of the leaf area in spring, and thus higher light interception, were discussed as causes for the breeding progress of sugar beet (Jaggard et al., 2007; Scott and Jaggard, 2000). However, no study has been conducted so far in which the breeding progress of sugar beet has been analyzed by taking into account all yield and technical quality parameters in one experimental approach. Therefore, the present study aimed at investigating the physiological causes of the breeding progress of sugar beet to identify possibilities for further yield increase. To exclude effects of cultivation measures and weather conditions, sugar beet varieties with different years of registration were cultivated simultaneously in field and greenhouse experiments. It was expected that breeding progress of sugar beet is mainly caused by an improved biomass partitioning (higher harvest index), light interception (LAI) and assimilation (rate of photosynthesis). Resistance and tolerance against pest and diseases as well as abiotic stress, which definitely contribute to the improvement of variety performance, were not considered in this study. A principle component analysis was conducted to analyze all parameters and their interactions. The changes in yield and quality parameters of varieties registered in different years are regarded as the real breeding progress of sugar beet.

## 2. Material and method

### 2.1. Varieties

Seeds of sugar beet varieties (*Beta vulgaris* L. subsp. *vulgaris*) (Lange et al., 1999) were provided by the Bundessortenamt and the breeding companies. In the greenhouse experiments, 17 varieties were tested. Because of limited seed availability, in the field trials only 8 varieties could be tested in 2007 and 11 varieties in 2008. The oldest variety was registered in 1964 and was taken as reference (100%) for the comparison. Further varieties were taken from the registration period 1964 to 2003 (Table 1). Even if they might not be fully representative for this period, they were the only varieties from which seeds were available.

### 2.2. Greenhouse experiments

In 2007 and 2008, 17 varieties were tested in a completely randomized pot experiment with 4 replicates. 12 pregerminated sugar beet seeds were put into 30 L plastic pots with 42 kg of sand. In the greenhouse were daylight conditions and the mean air temperature was 20 °C. Plants were irrigated every second day and received optimal nutrition supply according to Winner and Bürcky (1977). In order to obtain uniform plant establishment, seedlings were thinned after uniform emergence from 12 to 6, and finally to 2 plants per pot at the 4 leaf stage. Plants were kept free of pests and diseases. In 2007, plants were grown for 28 weeks and in 2008 for 26.5 weeks, to harvest taproots of 800–1000 g fresh weight, which is similar to the harvested yield in field trials.

### 2.3. Field trials

In 2007 and 2008, field trials with 8 and 11 sugar beet varieties, respectively, were conducted near Göttingen (51°25′ N, 9°54′ E) as a complete randomized block design with 4 replicates. From March to October the mean air temperature in 2 m height was 13.8 °C in 2008 and 13.7 °C in 2007, precipitation was 717 mm in 2007 and 410 mm in 2008. In both years the trials were conducted on loamy soils (Luvisol derived from Loess) on fields where sugar beet has not been cultivated for at least 20 years, so that a rhizomania infestation (BNYVV) could be excluded. Pelleted seeds were sown in 6 row plots of 8 m length on 31th March 2007 and 28th April 2008 with a plot drilling machine (Hege, Waldenburg, D). The distance within the row was 8 cm and between the rows 45 cm. After homogeneous emergence, the plants were thinned manually to a population density of 96,000 plants $ha^{-1}$ in the 4 to 6 leaf stage. N application