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Straw yield and saccharification potential for ethanol in cereal species and wheat cultivars

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ABSTRACT

Straw is a by-product from cereal production which constitutes a considerable biomass resource, for instance for 2G ethanol production. Straw yield per hectare and straw quality in terms of ethanol production are both important factors for the available biomass resource and the potential ethanol production per hectare. In a series of field trials on three locations in 2009, we compared straw and grain yield from the winter cereal species triticale, winter barley, winter rye, and winter wheat. Grain yield did not differ significantly between the species, but winter rye yielded up to 59% more straw dry matter than the other species. The release of glucose and xylose after pretreatment and enzymatic hydrolysis i.e. the saccharification potential was used to indicate the potential for ethanol production. The saccharification potential did not differ between species, but due to the differences in straw yield, areal saccharification potential (i.e. potential sugar production per hectare) was from 29% to 78% higher for winter rye than for other species. In a series of winter wheat cultivar trials on two locations in 2008 and three locations in 2009, straw yield differed significantly between cultivars in both years and across years. The highest yielding cultivar yielded up to 57% and 37% more straw than the lowest yielding cultivar in the two years, respectively, even among cultivars with non-significant differences in grain yield. The saccharification potential was measured from straw of winter wheat cultivar trials harvested in 2009. The potential varied largely but was not significantly affected by neither cultivar nor location. Due to cultivar differences in straw yield, however, areal saccharification potential differed significantly between cultivars with up to 38% difference in glucose yield and up to 35% in xylose yield. Straw yield increased with increasing grain yield, but the straw:grain ratio differed significantly between cultivars and was not consistent across years and locations. This has implications for straw resource estimates when these are based on the relationship between grain yield and straw yield. In conclusion, it appears possible to choose species and cultivars with higher straw yield and consequently larger potential for ethanol production per hectare without compromising grain yield. This may provide a means of increasing the overall straw resource, as long as increased straw yield is not accompanied by negative effects such as increased tendency to lodging.

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1. Introduction

Straw is normally considered a by-product from cereal production and constitutes a substantial resource in areas with extensive production of winter wheat (*Triticum aestivum* L.) and other cereal species. Some of the straw has traditionally been used for fodder and bedding in animal production, but it is increasingly being used for bioenergy. In Denmark, the proportion of the straw resource used for bioenergy has been steadily increasing, primarily for combustion in heating boilers or combined heat and power plants. As an average of the years 2006–2010, it is estimated that 30% of the overall straw resource was used for energy purposes, 32% was used in animal production etc., and 38% was left on the field [1]. With growing interest in bioenergy, we may expect an increased pressure on biomass resources including the straw resource, and an increasing proportion of the yet unutilized straw resource may be exploited in the future. However, extensive removal of straw from the field may reduce the soil carbon pool, which may lead to negative effects on soil fertility [2,3]. Whether straw is used for animal production, bioenergy, or for maintenance of the soil carbon pool, it is of interest to increase the straw resource. Thus, it may be relevant to increase straw yield per hectare, as long as it is not accompanied by negative effects on grain yield and on the sustainability of cereal production.

In contrast to grain yield, straw yield is rarely quantified. Estimation of the straw resource, therefore, often relies on assumptions about the relationship between grain yield and straw yield, i.e. straw yield is calculated by multiplying grain yield by a factor which is based on the ratio between straw yield and grain yield [4–6]. In order to understand the potential for increasing straw production, it is important to conduct quantitative measurements of straw yields on specific cultivars and species under different growing conditions.

Straw yield may be affected by many factors including water availability [7,8], nitrogen availability [8,9], sowing rate and sowing date [10], fungicide treatment [11] as well as cultivar [8,10,11] and certainly species. Breeding of cereals has primarily aimed at increasing grain yield. In addition, straw length has decreased, possibly as a consequence of breading programs increasing plant allocation to the grain, but also in order to avoid lodging. Even among new cultivars with high grain yield, however, considerable differences in straw length can be observed, and these differences may account for genetic differences in straw yield. If it is possible to choose cultivars with higher straw yield without negative effects on grain yield, this may constitute a mean of increasing the overall straw resource.

In the future, straw may be used for conversion technologies transforming the straw into biofuels rather than for combustion. These processes are usually categorized into processes based on the biochemical route e.g. ethanol production or biogas production and thermo-chemical route such as thermal gasification [12]. When using straw for 2G ethanol production, the saccharification potential, i.e. the release of glucose (a C6 sugar) and xylose (a C5 sugar) upon pretreatment and enzymatic hydrolysis, is of importance since potential ethanol production per hectare will depend on both straw yield and saccharification potential. Significant differences in saccharification potential have been found between winter wheat cultivars [13,14]. Differences in saccharification potential are also likely to exist between cereal species, but very little information is available regarding this. Recently, barley straw [15,16], rye straw [17] and triticale [18] have been assessed for ethanol production, but differences in pretreatment methods and hydrolysis conditions makes comparison difficult.

This study includes a series of trials with winter cereal species and a series of trials with winter wheat cultivars. The aim was to investigate variation in straw yield, straw saccharification potential, and the resulting areal saccharification potential among cereal species and among winter wheat cultivars. Besides, the aim was to study the relationship between straw yield and grain yield.

2. Materials and methods

2.1. *Species trials*

The species trial series comprised three trials in 2009 on different locations in Denmark (Table 1). All trials included four winter cereal species, i.e. triticale (*Triticale hexaploide* Lart.) cultivar Dinaro, winter barley (*Hordeum vulgare* L.) cultivar Zephyr, winter rye (*Secale cereale* L.) cultivar Evolo, and winter wheat cultivar Frument. The chosen cultivars were selected to represent the most commonly used cultivars of each species at the time of the trials, and Frument, for example, was the most extensively grown winter wheat cultivar in Denmark in 2009.

The trials were designed as randomized block designs with four replicates or blocks. In each trial, all species were sown on the same day, and the trials were sown within the period 18th to 26th September 2008. Herbicides and fungicides were applied according to standard practice for each of the four species. The quantity of nitrogen fertilizer was applied according to the general regulation of fertilization of crops in Denmark which depends on both crop species and soil type (Table 1). On average of the three trials, nitrogen application was 145 kg ha^{-1} for winter rye, 166 kg ha^{-1} for winter barley, 169 kg ha^{-1} for triticale, and 189 kg ha^{-1} for winter wheat.

Within trials, all species were harvested on the same day, except in Storvorde where winter barley was harvested earlier than the other species. In Holstebro and Vojens, winter barley was subject to some lodging, primarily because the harvest was postponed until the time of ripeness of the other species in these trials. Due to technical problems, straw yield data was missing for winter rye in the trial in Vojens and for winter barley in the trial in Storvorde.

2.2. *Cultivar trials*

Straw production was studied in selected winter wheat cultivars and selected trials in the official Danish cultivar testing program in 2008 and 2009. The cultivar trials comprised a large number of cultivars (Table 1) for which grain yield is being measured as a standard but straw yield is not being measured. Therefore, we chose a selection of cultivars for additional