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Selection and hydroponic growth of bread wheat cultivars for bioregenerative life support systems

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Abstract

As part of the ESA-funded MELiSSA program, the suitability, the growth and the development of four bread wheat cultivars were investigated in hydroponic culture with the aim to incorporate such a cultivation system in an Environmental Control and Life Support System (ECLSS). Wheat plants can fulfill three major functions in space: (a) fixation of CO_2 and production of O_2, (b) production of grains for human nutrition and (c) production of cleaned water after condensation of the water vapor released from the plants by transpiration. Four spring wheat cultivars (Aletsch, Fiorina, Greina and CH Rubli) were grown hydroponically and compared with respect to growth and grain maturation properties. The height of the plants, the culture duration from germination to harvest, the quantity of water used, the number of fertile and non-fertile tillers as well as the quantity and quality of the grains harvested were considered. Mature grains could be harvested after around 160 days depending on the varieties. It became evident that the nutrient supply is crucial in this context and strongly affects leaf senescence and grain maturation. After a first experiment, the culture conditions were improved for the second experiment (stepwise decrease of EC after flowering, pH adjusted twice a week, less plants per m^2) leading to a more favorable harvest (higher grain yield and harvest index). Considerably less green tillers without mature grains were present at harvest time in experiment 2 than in experiment 1. The harvest index for dry matter (including roots) ranged from 0.13 to 0.35 in experiment 1 and from 0.23 to 0.41 in experiment 2 with modified culture conditions. The thousand-grain weight for the four varieties ranged from 30.4 to 36.7 g in experiment 1 and from 33.2 to 39.1 g in experiment 2, while market samples were in the range of 39.4–46.9 g. Calcium levels in grains of the hydroponically grown wheat were similar to those from field-grown wheat, while potassium, magnesium, phosphorus, iron, zinc, copper, manganese and nickel levels tended to be higher in the grains of experimental plants. It remains a challenge for future experiments to further adapt the nutrient supply in order to improve senescence of vegetative plant parts, harvest index and the composition of bread wheat grains.

Keywords: Bread wheat; Grain maturation; Harvest index; Nutrient economy; Tillers; Senescence

1. Introduction

The ESA MELiSSA (European Space Agency – Micro Ecological Life Support System Alternative) project "is intended to be a tool to gain understanding of closed life-support systems, and consequently a knowledge base for European development of regenerative life-support systems for long-term manned missions (e.g. lunar base, Mars mission)" as said by Lasseur et al. (2010). As a part of the ESA-MELiSSA project, the MELiSSA Food Characterization Program (MFC) focuses on growing plants for food production on long-term space missions. In this program four energy-rich crops, bread wheat, durum wheat (Stasiak et al., 2012), potato (Molders et al., 2012) and soybean (De Micco et al., 2012) were grown and screened for their performances. The experiments reported here focused on bread wheat (*Triticum aestivum*) cultivar selection and grain production.

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Bread wheat cultivation in space fulfills three major functions: (a) CO_2 assimilation and production of O_2, (b) production of high-quality grains for human nutrition, and (c) supply of cleaned water after condensation of water vapor produced by transpiration (Bubenheim, 1991; Galston, 1992; Wheeler et al., 2008; Wheeler et al., 2011). The cultivation of plants in space (closed environment) or in the field depends on different environmental factors. The requirements for growing plants in an Environmental Control and Life Support System (ECLSS) with the final aim to produce food during long-term space missions were analyzed based on past experiences (e.g. Salisbury et al., 1987; Mackowiak et al., 1989; Heberer and Below, 1989; Wheeler et al., 1996; Steinberg et al., 2000; Wheeler et al., 2003) to obtain selection criteria for the cultivars.

Soil-free (hydroponic) culture techniques are requested for growing wheat in space. In soil, nutrients may be present in organic (e.g. nitrogen, sulfur) or inorganic (e.g. potassium, magnesium, phosphorous) reserves and as such not directly available for plants. While plants in a field may influence nutrient availability to some extent by the release of root exudates or by root growth and exploration of new soil regions (Marschner, 1995), all nutrients in hydroponic culture are directly available for the roots of growing plants. Therefore the nutrient medium must be adequately composed and the nutritional status of the plants must be kept in mind. Nutrient deficiencies can be detected in a non-destructive manner through diagnostic tools such as spectral reflectance (Ayala-Silva and Beyl, 2005).

The duration of a generation from germination to grain maturity and the plant height are two key factors for properly planning the infrastructure requested to grow wheat in space. Beside the nutrient economy, technical aspects of growing and harvesting the plants are important for bread wheat production. In this context, lodging of plants, tiller formation, water use, harvest index (accumulation of dry matter in the harvested grains compared to the total biomass in the plant), senescence properties and the simultaneous maturation of the spikes are key aspects referring to plant development. A further set of criteria concerns the quality of the harvested grains and includes grain yield per illuminated surface, grain composition (organic compounds and minerals relevant for human nutrition) and the germination properties for the subsequent production of sprouts.

During the growth of wheat plants, initially there is only the main shoot and new leaves at the top of this shoot emerge sequentially. Additionally, tillers emerge from the main shoot or from previously emerged tillers and can considerably contribute to the overall above-ground biomass. One plant can bear several spikes, but there might be also tillers formed without spikes or with empty spikes containing no maturing grains (Simmons, 1987). Such tillers accumulate biomass without contributing to yield. Besides the illumination, nitrogen availability is a key factor influencing tiller formation (White and Wilson, 2006; Evers et al., 2010). Wheat genotypes with no or only a few non-fertile tillers and with a high grain yield are interesting for the production of grains in space.

The experiments reported here were performed to identify and characterize suitable bread wheat cultivars for the cultivation in an Environmental Control and Life support System (ECLSS). The growth and the behavior of these four bread wheat cultivars were analyzed with the purpose to obtain a ranking of the best performing bread wheat cultivars. The wheat plants were grown in a recirculating hydroponic system in which the nutrients were directly available for the plants. Therefore the nutrients should be carefully supplied. The optimization of the hydroponic cultivation (electrical conductivity and pH of the nutrient solution) for the second experiment – with the aim to improve the harvest index – was an important aspect of this study.

2. Materials and methods

2.1. Cultivar selection

The bread wheat cultivars used for these experiments were selected to fulfill criteria considered to be important for bioregenerative life support systems. These criteria were: high yield, precocity of spike emergence, short generation time, low plant height, resistance to lodging, disease resistance, high grain quality and no need for vernalization. Based on these criteria, four spring wheat varieties (*Triticum aestivum* L. cv. Aletsch, cv. Fiorina, cv. Greina and cv. CH Rubli, certified seed material, obtained in 2009 from Eric Schweizer AG, Thun, Switzerland for Fiorina, Greina and CH Rubli, and from Delley Seeds and Plants Ltd, Delley, Switzerland for Aletsch) were selected from a list of 28 spring and winter wheat genotypes (Schwärzel et al., 2008). Table 1 shows the key parameters based on field performance of the four spring wheat cultivars selected.

2.2. Plant material

The seeds were sterilized by immersing in 70% ethanol for 2 min and then shaken gently in 20% commercial bleach for 10 min. Afterwards they were rinsed 5 times with sterile deionized water. Seeds were then germinated in the dark on wet filter paper (deionized water) for two to four days (depending on the cultivars) until they got the same developmental stage (radicle and coleoptile just emerged from seed, Zadok's growth stage 07). Seedlings were then placed in the stonewool with the recirculating nutrient medium (see below).

2.3. Growth conditions and hydroponic system

Wheat was grown in polyurethane coated stainless steel gullies (1 m long, 19 cm wide, 6.5 cm high) in stonewool (Grodan, reference AO 25/40 10/10 W) using a recirculating nutrient film technique (NFT) delivery system (Fig. 1). Seedlings were sown at a planting density of 60 seeds per gully (15