Evaluation of KTJT-1, an early-maturing mutant of sweet sorghum acquired by carbon ion irradiation (Postprint)

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Abstract

Sweet sorghum has the potential of becoming a useful energy crop. An early-maturity mutant of sweet sorghum, KFJT-1, was obtained by carbon ions irradiation of KFJT-CK, a wild plant. In this paper, we evaluate the mutant from the length and fresh weight of radicle and leaves after seed germination, the growth rate at the elongation stage, and the internodal parameters under field trail condition. The results showed that the seedling growth of KFJT-1 was inhibited by carbon ions irradiation, and the leaf length, the fresh weight of radicle and leaves from KFJT-1 decreased by 15.32%, 76.27%, and 27.08% than those of KFJT-CK, respectively. However, the growth rate of KFJT-1 on July 12, July 27 and August 1 increased by 16.19%, 59.28% and 26.87%, respectively, compared with the KFJT-CK. The stalk diameter, total biomass yield and sugar content of KFJT-1 was higher than those of KFJT-CK, despite that the plant height of KFJT-1 was significantly less than KFJT-CK ($P<0.05$). In addition, KFJT-1 differed from KFJT-CK in the internodal length, weight and sugar content. In conclusion, the early-maturity mutant of KFJT-1 will be a promising variety for sweet sorghum industrialization in Gansu province, China.

Full Text

Preamble

Evaluation of KFJT-1, an Early-Maturity Mutant of Sweet Sorghum Acquired by Carbon Ion Irradiation

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Abstract

Sweet sorghum has the potential to become a useful energy crop. An early-maturity mutant of sweet sorghum, KFJT-1, was obtained by carbon ion irradiation of KFJT-CK, a wild-type plant. In this paper, we evaluate the mutant based on the length and fresh weight of radicle and leaves after seed germination, the growth rate at the elongation stage, and internodal parameters under field trial conditions. The results showed that seedling growth of KFJT-1 was inhibited by carbon ion irradiation, with leaf length, fresh weight of radicle, and fresh weight of leaves decreasing by 15.32%, 76.27%, and 27.08%, respectively, compared to KFJT-CK.

However, the growth rate of KFJT-1 on July 12, July 27, and August 1 increased by 16.19%, 59.28%, and 26.87%, respectively, compared with KFJT-CK. The stalk diameter, total biomass yield, and sugar content of KFJT-1 were higher than those of KFJT-CK, despite the plant height of KFJT-1 being significantly less than KFJT-CK ($P < 0.05$). In addition, KFJT-1 differed from KFJT-CK in internodal length, weight, and sugar content. In conclusion, the early-maturity mutant KFJT-1 will be a promising variety for sweet sorghum industrialization in Gansu Province, China.

Keywords: Sweet sorghum, Early maturity, Carbon ions, Evaluation
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INTRODUCTION

Growing concerns over oil supply security and the negative environmental impacts of fossil fuels have created urgent pressure to develop renewable fuel alternatives [1]. In recent years, increasing attention has been devoted to converting biomass into fuel ethanol, which is considered the cleanest liquid fuel alternative to fossil fuels [2]. As a feedstock for fuel ethanol, sweet sorghum [*Sorghum bicolor* (L.) Moench] is a high biomass- and sugar-yielding crop with high photosynthetic efficiency [3], and has the potential to become a useful energy crop [4–7]. However, high-quality raw materials are the focus and lifeline of sweet sorghum industrialization. In fact, the scarcity of excellent varieties inhibits the sustainable development of sweet sorghum industrialization.

Ion beams, as a new source of mutation, are characterized by higher mutation rates and broader mutational spectra with less damage to irradiated organisms, leading to the widespread use of ion beam mutation technology in crop breeding [8]. In breeding practice, plant breeders seek varieties with high production, high quality, and strong stress resistance. Some mutants induced by ions may be applied directly to production [9]. At the Institute of Modern Physics (IMP), Chinese Academy of Sciences, heavy ion plant breeding practices include various crops such as wheat, corn, vegetables, herbage, and flowers, as well as antibiotics. One heavy-ion-improved wheat variety has been planted on a large scale in local regions after strict authentication, and many favorable flower mutants have also been acquired after heavy-ion irradiation [10].

In response to China's strategic demand for energy, IMP has devoted itself to the industrialization of bioethanol from sweet sorghum since 2006, using the Heavy Ion Research Facility in Lanzhou (HIRFL) for variety improvement through mutation breeding technology [11, 12]. An early-maturity mutant, KFJT-1, has been selected at a dose of 80 Gy, with a growth period about 20 days shorter than that of KFJT-CK, a wild-type plant. Currently, KFJT-1 has been planted for five generations in Gansu and Hainan provinces, China, with the latter serving as the southern breeding base for northern breeders. In this paper, we evaluate the KFJT-1 mutant in terms of radicle and leaf length and fresh weight after seed germination, growth rate at the elongation stage, internodal parameters under field trial conditions, and agronomic traits, to provide basic data for further regional evaluation trials and mutation mechanism research.

MATERIALS AND METHODS

A. Plant Materials

The early-maturity mutant KFJT-1 was acquired in 2006 by irradiating KFJT-CK seeds with 100 MeV/u ^{12}C ion beams from HIRFL at a dose of about 20 Gy min^{-1} to a total dose of 80 Gy.

B. Trial Site and Design

In 2008 and 2009, field trials of KFJT-1 and KFJT-CK were conducted at the botany garden of Lanzhou University (36°40 N, 103°49 E; 1520 m above sea level) in Gansu Province, China. In the experiments, each variety was planted under plastic film mulching cultivation with a plot size of 25 m^2 (5 m × 5 m bed comprising five rows). The spacing was 50 cm between ridges and 24 cm between plants.

C. Sampling and Measurement

For radicle and leaf length and fresh weight, seeds of KFJT-1 and KFJT-CK were sterilized for 10 min in 0.1% HgCl solution and washed five times with sterilized water. During germination, 100 seeds of equal size without mold or lesions were selected from each of KFJT-1 and KFJT-CK. The germinating seeds were placed in a 90 mm Petri dish containing double-layer wet filter paper and germinated at (25 ± 2) °C in a growth chamber under a 16-h photoperiod provided by fluorescent light tubes (50 µmol m^{-2} s^{-1}). After germinating for 7 days, 10 plants were chosen from each Petri dish to measure the length and fresh weight of radicles and leaves.

For growth rate at the elongation stage, plant height was measured every five days from July 7 to August 1 on eight fixed plants each of KFJT-1 and KFJT-CK. For internodal parameters, five plants were sampled using a random method.

When matured, internodal parameters were measured, including length, weight, and sugar content of different internodes.

D. Statistical Analysis

All statistical analyses were conducted using SPSS 13.0 software. The data, collected in at least triplicate ($n \geq 3$), were expressed as means ± standard deviation. To assess the statistical significance of treatment differences, one-way analysis of variance (ANOVA) followed by Duncan' s multiple range test ($P < 0.05$) was employed. Figures were plotted with Origin 7.5 software.

RESULTS AND DISCUSSION

A. Length and Fresh Weight of Radicle and Leaves

Figure 1 shows that, compared to KFJT-CK, seedling growth of KFJT-1 was inhibited by carbon ion irradiation, which resembles previous studies [12, 14, 15]. Although KFJT-1 did not differ significantly from KFJT-CK in radicle length ($P < 0.05$), dramatic radiation effects were observed on leaf length (Fig. 1(a)) and fresh weight of radicles and leaves (Fig. 1(b)) seven days after germination. The leaf length and fresh weight of radicles and leaves from KFJT-1 were 15.32%, 76.27%, and 27.08% less than those of KFJT-CK, respectively. ANOVA showed significant differences between KFJT-1 and KFJT-CK ($P < 0.05$).

In the plant life cycle, seeds have the highest resistance to extreme environmental stresses, whereas seedlings are most susceptible [16]. The leaf length and fresh weight of radicles and leaves of KFJT-1 were significantly inhibited due to physiological damage induced by carbon ions, similar to results observed with salinity stress [17].

B. Growth Rate in Elongation Stage

The elongation stage of sweet sorghum is a key plant growth period [18]. Our previous research indicated that the average growth rate reached 12 cm/day for the sweet sorghum cultivar 'Wray' during July 20–26 [19]. In this study, plant height of KFJT-1 and KFJT-CK showed an obvious rising trend during the elongation stage (Fig. 2(a)). However, plant height of KFJT-1 was much less than that of KFJT-CK. The average daily height growth was 6.2 cm for KFJT-CK, faster than that of KFJT-1, which had a corresponding value of 5.8 cm from July 7 to August 1. Interestingly, further study found that KFJT-1 excelled KFJT-CK in growth rate on July 12 and 27, and August 1, with increases of 16.19%, 59.28%, and 26.87%, respectively (Fig. 2(b)).

C. Internodal Length, Weight, and Sugar Content

The stems of KFJT-1 and KFJT-CK showed different patterns at harvest period in their internodal length, weight, and sugar content. As shown in Fig. 3(a), from the first node to the ninth node, each internodal length of KFJT-CK was significantly higher than that of KFJT-1 ($P < 0.05$), whereas each internodal length of KFJT-CK from the tenth node to the thirteenth node was less than that of KFJT-1. In Fig. 3(b), the internodal weight of KFJT-1 was obviously higher than that of KFJT-CK ($P < 0.05$), and the node weight of KFJT-1 and KFJT-CK varied similarly with internodal number, reaching maximum internodal weight at the fourth node (119.3 g for KFJT-1 and 98.3 g for KFJT-CK). Fig. 3(c) shows the internodal sugar content of KFJT-1 and KFJT-CK; from the first node to the tenth node, each internode of KFJT-1 had significantly higher sugar content than that of KFJT-CK ($P < 0.05$).

D. Stalk Size, Biomass Yield, and Sugar Content

The main agronomic features of KFJT-1 and KFJT-CK are given in Table 1, including plant height, stalk diameter, total biomass yield, and sugar content. While plant height of KFJT-1 was 22.92% less than KFJT-CK, the stalk diameter, total biomass yield, and sugar content of KFJT-1 were 3.99%, 4.69%, and 7.85% higher than those of KFJT-CK, respectively.

Plant breeding is now based on creating variation, and the use of nuclear techniques in plant breeding has been directed primarily toward inducing mutation [20]. Heavy ion beams, as a new mutagen, provide a broad variation spectrum, and the variants can be used as plant breeding materials [14]. The evaluated early-maturity mutant KFJT-1, induced by carbon ion irradiation, is advantageous over KFJT-CK in total biomass yield and sugar content. However, carbon ion irradiation may induce physiological damage to sweet sorghum seeds, hence the obvious inhibition of radicles and leaves of KFJT-1 and the reduced plant height and internodal length.

In conclusion, despite the shorter plant height of KFJT-1 compared to KFJT-CK, the total biomass yield of KFJT-1 increased to 78 t ha^{-1} due to its greater stalk diameter and internodal weight. Additionally, the sugar content of KFJT-1 was higher than that of KFJT-CK.

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