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*Full Length Research Paper*

# Evaluation of seven jojoba *(Simmondsia chinensis)* clones under Qassim Region conditions in Saudi Arabia

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**This study was conducted at the Experimental Farm of the College of Agriculture and Veterinary Medicine, Qassim University to evaluate growth, vegetative, reproductive and seed yield characters. Seven diverse female jojoba genotypes were used and established in the field experiment between October 27 and 30, 2008. Sixty plants per genotype were planted in completely randomized block design with five replications. The genotypes significantly differed for all studied traits. Highly significant differences among growth seasons and genotypes were found for plant height. Plant height measurements showed that growth rate was rapid in May and September, after September, growth rate was gradually decreased until February 1st. Genotypes, $HA_9$ and $HD_1$ recorded the highest and lowest values of plant height respectively. For plant diameters axis, genotypes $HB_8$ and $HD_1$ had the broadest and narrowest diameter respectively. Genotypes $HB_8$ and $MD_8$ had almost similar values in most traits. $HB_2$ had the greatest number of branched nodes, total nodes, number of flower buds and flowers, number of total leaves per branch, while it had the shortest branch length and internodes. Genotype $HB_8$ was superior in branch length, branch dry weight, longest internodes length, seed yield plant$^{-1}$ and seed weight. Differences in flowering initiation were also found among the seven genotypes investigated. Results reported in this research could permit further improvement by selection and breeding.**

**Key words:** Genotype, reproductive, simmondsin, *Simmondsia chinensis*, biometric traits, yield.

## INTRODUCTION

Jojoba (*Simmondsia chinensis* [Link] Schneider) is an evergreen shrub that is native to northern México and the southwestern United States. Its natural distribution falls between latitudes 25 and 34 in an area which closely approximates the Sonorant Desert (Gentry, 1958). The jojoba plant has economic value because its seeds contain about 50% of a light yellow, odorless wax ester commonly referred to as jojoba oil, which is extensively used in the cosmetic industry due to dermatological properties. Its great resistance to drought allows this shrub to produce a crop with significantly less water than is necessary for traditional crops. According to Yermanos (1982), 250-450 mm of annual rainfall were adequate for survival of natural jojoba population. In experimental farms, however, vegetative growth and its components were reported to vary with the intensity of drought stress (Nerd et al., 1982; Benzioni and Nerd, 1985; Nerd and Benzioni, 1985; Malende, 1989; Nelson et al., 1993; Nelson, 1996; Osman and AboHassan, 2002). Moreover, jojoba is relatively salt tolerant (Roussos et al., 2006). Roussos et al. (2007) reported that jojoba explants tolerate salinity up to a level of sodium chloride concentration (113 mM), without showing any stress symptoms.

It is well known that shortage of irrigation water is one of the main factors that limit crop production in arid and semi arid environment. Plants suffer from water-stress not only under drought and high salinity conditions but also under low or high temperature. Consequently, utilization of drought and salinity tolerant shrubs in sand stabilization and landscaping and greenification projects, in establishing open natural range lands and national parks will save adequate amounts of fresh water that can be used for cultivation of traditional field crops. Osman and Abohassan (1997) reported that jojoba in western Saudi Arabia, as its original habitat, had maintained positive growth under high drought stress. The ability to withstand drought could be attributed to its capability to cope with environmental changes through morphological modification such as reduction in leaf area and increase in leaf thickness or leaf weight.

The growth of jojoba is controlled by various agro-climatic factors, for example, temperature, soil type, salinity level of soil, water and methods of sowing (Younus et al., 2003). Many researchers studied growth and seed yield characters in jojoba, (Nelson and Bartels, 1998; Benzioni et al., 1999; Tobares et al., 2004; Bashir et al., 2007, 2009; Prat et al., 2008; Hussain et al., 2011; Osman and Abohassan, 2013). As it occurs in other crops, the jojoba industry faces the challenge of finding ways to improve productivity and quality of the products. In addition, the seedlings cannot be sexed until the first flower buds appear 9 to 24 months after sowing (Dunstone and Begg, 1983). Although jojoba plants start producing fruit in 3 years, full maturity takes 10 to 12 years, with the plant's life estimated to be 100 years (Verbanic, 1986). Only a small proportion (less than 1%) of the plant population originating from seeds of native plants has the potential of yielding economically acceptable yields (Purcell and Purcell, 1988). Hence, the best method for jojoba improvement, in the short term, is the selection of plants with desirable characteristics and propagating them asexually. The objective of this study was to evaluate jojoba plants for agronomic and yield characters to introduce jojoba as a commercial crop with the purpose of selecting superior jojoba genotypes for Qassim Region.

## MATERIALS AND METHODS

### Field experimental site

The field experiment was carried out in the Experimental Farm of the College of Agriculture and Veterinary Medicine, Qassim University. It has 26° 18' N latitude and 43° 58' E longitude, and 725 m above sea level, in central Saudi Arabia. Soil samples from the experimental site before jojoba planting were taken for mechanical and chemical analysis. Samples were taken from the irrigated soil near the plant to a depth of 0 - 30 cm. The soil properties are shown in Table 1.

Meteorological data at the experimental site during the growing seasons were obtained from the meteorological station near the Experimental Farm of the College of Agriculture and Veterinary Medicine, and data are shown in Table 2.

### Plant material and experimental design

Plant material (male and female) were provided by Faculty of Meteorology–King Abdulaziz University. The materials for this study comprised seven diverse female jojoba genotypes (*Simmondsia chinensis.)* selected for their characters. In the last decade, a comprehensive jojoba selection program was conducted at Faculty of Meteorology – King Abdulaziz University. In this program, promising individual plants were vegetatively propagated and planted at some regions in Saudi Arabia (Al-Medinah, Hail, HadoAl-Sham). The most promising clones, based on the selection criteria, were propagated by cuttings. Seven genotypes (HD1, HA9, HB2, HB4, HB6, HB8, and MD8) were chosen based on their desirable characters.

The plants were established in the field experiment between October 27 and 30, 2008. Sixty plants per genotype were planted in completely randomized block design with five replications. Each replicate consisted of 4 rows, each containing 26 plants (21 plants represent seven genotypes, two and three plants as border for west and east direction respectively). Distances between rows and within plants in rows were 3 and 2 m, respectively. Rows ran in an east-west direction. Male plants were repeated one row every six female rows of mixed males and female plants developed from seeds derived from a mixed population. Before sowing, an irrigation drip system was installed in the experimental area. The irrigation treatment is administered once every ten days to provide water based on estimated seasonal evapotranspiration. Fertilizer was applied with 100 g Diammonium Phosphate (DAP) per plant twice during growing season. Weeds between-plants were removed by hand and those between rows are easily controlled by cultivation.

### Parameters

Parameters were recorded to achieve the objectives of this experiment for measuring plant growth and yield characters of jojoba genotypes. These parameters are measured as follows:

#### *Growth analysis*

For each genotype, four plants per block (from the inner rows) were randomly chosen and tagged for growth measurements. At March 1st, 2010, plant height above the ground was measurements and was repeated monthly. For each tagged plant, two diameters (North–South axis and East–West axis) were recorded every three months, starting with April 1st 2010, representing four consecutive seasons (Spring, Summer, Autumn and Winter).

#### *Vegetative and reproductive measurements*

Data were collected from tagged plants of each genotype for each block. One branch was selected from the mid-level of the plants for detailed analysis. On each branch,

**Table 1.** Mechanical and chemical properties of the soil samples before jojoba planting.

| Mechanical analysis | | | Chemical analysis | | | | | Soil texture class |
|---|---|---|---|---|---|---|---|---|
| Sand % | Silt % | Clay % | Ec (ppm) | pH | N (ppm) | P (ppm) | K (ppm) | |
| 64.68 | 25.37 | 9.96 | 49.68 | 9.54 | 6.99 | 3.98 | 85.73 | Sandy loamy |

the terminal 10 nodes with leaves longer than 1 cm were studied. The following data were collected: branch length (cm), branched nodes, total number of nodes on main (10) plus secondary branches, branch dry weight (g), internodes length (cm), total number of leaves, total leaves dry weight (g), leaf length (cm), leaf width (cm), length: width ratio and number of flower buds and flowers. Flowering date was recorded as number of days after October (DAO) to when plants that are bearing open floral buds (with a visible stigma).

Seeds were harvested from the previous tagged plants by hand at full maturity in the 2nd week of May 2010, 4th week of May 2011 and 1st week of June 2012. Harvested seeds were cleaned, dried and weighed and used for determining seed yield plant$^{-1}$ (g) and seed weight (g).

### Statistical analysis

Data collected for plant height and diameters statistically analyzed according to the technique of analysis of variance (ANOVA) showed that for one factor randomized, complete block design combined over growth periods and one factor randomized complete block design (RCBD) for each date to test the differences among growth periods and genotypes within each date, respectively. Moreover, data for other characters were analyzed statistically using RCBD. Where a significant *F*-test was found the mean values were separated using Duncan's multiple range test. All analyses of variance were computed using the MSTATC microcomputer program (MSTATC, 1990).

## RESULTS AND DISCUSSION

### Growth analysis

Based on the combined analysis of variance for growth analysis characters, the results revealed the presence of highly significant differences among periods and genotypes on plant height above ground and plant diameters at different dates in seven jojoba genotypes (Table 3). These indicate that the behavior of the same genotype differed from one month to another and at the same month, the genotypes differed in their traits.

Data in Table 3 showed that plant height ranged from 58 cm (March 1st, 2010) to 94.5 cm (February 1st, 2011). Plant height measurements showed that growth rate was rapid in May and September, decreased in June and July. After September, growth rate gradually decreased until February, concordant with the experience of Nelson and Bartels (1998). The average growth increment of plant height from March 1st 2010 to February 1st 2011 was 36.1 cm (about 62%). In the periods which decreased growth, no significant differences among months were observed (Table 3). These levels of plant height growth rate can be considered very good when they are compared with the results obtained by Prat et al. (2008). These authors recorded that the total growth increment of plant height ranged from 18.6 to 26.8 cm at 360 days. The genotypes significantly differed in plant height based on average of all months (Table 3), therefore, the comparisons between genotypic means are valid. Plant height above ground among jojoba genotypes ranged from 67.1 cm ($HD_1$) to 86.2 cm ($HA_9$), based on average over months (Table 3). Bashir et al. (2007) recorded different growth parameters among jojoba strains. Also, Prat et al. (2008) studied the effect of plant growth regulators on jojoba and recorded that the total growth increment of plant height ranged from 18.6 to 26.8 cm at 360 days post-application. Moreover, Nelson and Bartels (1998) reported that plant height measurements showed that growth was rapid in April and May, but decreased in June and July and then generally remained slow until the following spring.

Significant differences were observed on plant diameters among all evaluation dates (Table 3). The two plant diameters axis (North–South axis and East–West axis) had almost the same values at all evaluation dates. Table 8 shows the plant diameters axis, based on the average two diameters which ranged from 81.7 cm (April 1st, 2010) to 126.2 cm (January 1st, 2011). The average growth increment of plant diameters axis, based on average two diameters from April 1st 2010 to January 1st 2011 was 44.5 cm (about 54.5%). Prat et al. (2008) studied the effect of plant growth regulators on jojoba and recorded that the total growth increment of plant diameters axis, ranged from 11.6 to 18.3 cm at 360 days.

The genotypes significantly differed in plant diameters based on average of all dates (Table 3). Plant diameters axis for seven jojoba genotypes ranged from 93.5 cm ($HD_1$) to 114.3 ($HB_8$), based on average over dates and two diameters. No significant differences in the two diameters among genotypes, $HB_8$ and $MD_8$, were detected.

Genetic differences among genotypes in plant height and plant diameters have previously been reported (Botte et al., 1998; Benzioni et al., 1999; Tobares et al., 2004; Prat et al., 2008). Benzioni et al. (1999) found that some clones exhibited excellent vegetative traits related to yield potential, such as, rapid growth and extensive branching.

**Table 2.** Monthly mean air temperature, mean relative humidity (RH %) and precipitation (mm/month) at the experimental sites for the three seasons.*

| Month | 2010 season | | | | 2011 season | | | | 2012 season | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temperature °C | | RH % | Precipitation | Temperature °C | | RH % | Precipitation | Temperature °C | | RH % | Precipitation |
| | Mean | Extreme | | | Mean | Extreme | | | Mean | Extreme | | |
| Jan | 16 | 3-31 | 58 | 2.7 | 14.6 | 2-26 | 67.8 | 34.3 | 14.2 | 0-28 | 52.0 | 0.0 |
| Feb | 19 | 0-34 | 46 | 1 | 17.7 | 5-32 | 50.2 | 0.0 | 16.4 | 3-33 | 47.0 | 7.7 |
| Mar | 22 | 8-39 | 35 | 0 | 19.5 | 4-36 | 39.1 | 8.7 | 19.0 | 4-37 | 38.0 | 3.8 |
| Apr | 27 | 13-41 | 48 | 27.9 | 25.1 | 12-39 | 45.9 | 46.4 | 26.8 | 14-39 | 40.0 | 7.1 |
| May | 32 | 17-45 | 34 | 16.4 | 32.3 | 18-45 | 29.1 | 2.8 | 33.6 | 20-45 | 22.0 | 2.2 |
| Jun | 36 | 23-47 | 18 | 0 | 35.6 | 23-46 | 20.0 | 7.7 | 35.4 | 23-47 | 18.0 | 0.0 |
| Jul | 37 | 23-48 | 20 | 0 | 35.6 | 25-48 | 18.2 | 0.0 | 37.4 | 25-48 | 19.0 | 0.0 |
| Aug | 37 | 24-47 | 19 | 0 | 36.6 | 25-48 | 19.5 | 0.0 | 36.6 | 25-46 | 20.0 | 0.0 |
| Sep | 34 | 21-47 | 22 | 0 | 33.9 | 23-45 | 21.3 | 0.0 | 33.2 | 21-46 | 22.0 | 0.0 |
| Oct | 29 | 16-41 | 30 | 0 | 27.5 | 15-42 | 29.0 | 0.0 | 28.7 | 18-41 | 29.0 | 0.0 |
| Nov | 20 | 5-36 | 35 | 0 | 18.4 | 2-33 | 50.5 | 59.3 | 21.0 | 7-35 | 59.0 | 32.9 |
| Dec | 15 | 1-28 | 46 | 10.2 | 14.3 | 1-27 | 53.4 | 0.0 | 16.6 | 5-29 | 76.0 | 23.0 |

*** Source:** According to Presidency of Meteorology and Environmental.

Significant variation among genotypes in plant height was observed within each month for all dates from March 1st 2010 to February 1st 2011 (Table 4). Genotype $HA_9$ was the tallest genotype in most months, while genotype $HD_1$ was the shortest one in all cases. Genotypes $HB_8$ and $MD_8$ had almost similar values in most cases. These levels of plant height growth can be considered very good when they are compared with the results obtained by Botti et al. (1998). These authors measured plant height of jojoba genotypes, when the plants were 2-years old and recorded that plant height ranged from 43.3 to 75.0 cm as compared with our results which ranged from 77.3c to 100.7cm (November 1st, 2010).

Younus et al. (2003) stated that the growth of jojoba is controlled by various agro-climatic factors such as temperature, soil type, salinity level, water and method of sowing.

Significant variation among genotypes was observed for plant diameter within each date (Table 5). Genotypes $HB_8$ and $MD_8$ had the broadest diameter at all dates, while genotype $HD_1$ had the narrowest diameter in most cases. No significant differences between the two clones $HB_8$ and $MD_8$ were detected for all growth periods. This result confirmed the previous finding which indicated that these two genotypes had similar values for plant height and plant diameters. These results are similar to the report on the presence of significant differences among clones on plant diameters (Prat et al., 2008).

## Vegetative and reproductive measurements

### *Branch traits*

Increase in branch length is the result of cell division and elongation. Table 6 reveal significant differences among seven genotypes in vegetative traits (branch length, branched nodes, total number of nodes, branch dry weight and internodes length). Genotype $HB_8$ showing more branch lengthening, heaviest branch dry weight and longest internodes. Moreover, genotype $HB_2$ had greater number of branched nodes and total nodes, while it had the shortest branch length and internodes. Lightly, branch dry weight was obtained by genotype $HA_9$ and the lowest number of total nodes was found with genotype $HD_1$. These results indicated that each genotype has a different genetic character and their responses vary with climatic and soil conditions depending on genotype.

### *Leaf measurements*

All leaf parameters showed significant differences among the genotype for all traits (Table 7). Genotype $HB_2$ had the highest number of total

**Table 3.** Effect of growth period and genotypes on plant height above ground and plant diameters (North–South axis and East–West axis), for seven jojoba genotypes from March 1st 2010 to Feb 1st 2011.

| Treatment | Plant height (cm) | Plant diameters (cm) | |
|---|---|---|---|
| | | North–South axis | East–West axis |
| **Month** | | | |
| Mar 1st 2010 | $58.0^{i}$ | | |
| Apr 1st 2010 | $62.9^{h}$ | $81.8^{d}$ | $81.6^{d}$ |
| May 1st 2010 | $66.0^{g}$ | | |
| Jun 1st 2010 | $71.6^{f}$ | | |
| Jul 1st 2010 | $74.6^{e}$ | $97.1^{c}$ | $96.8^{c}$ |
| Aug 1st 2010 | $76.6^{e}$ | | |
| Sep 1st 2010 | $81.4^{d}$ | | |
| Oct 1st 2010 | $86.8^{c}$ | $116.6^{b}$ | $116.6^{b}$ |
| Nov 1st 2010 | $90.8^{b}$ | | |
| Dec 1st 2010 | $92.8^{ab}$ | | |
| Jan 1st 2011 | $93.8^{a}$ | $126.6^{a}$ | $125.8^{a}$ |
| Feb 1st 2011 | $94.5^{a}$ | | |
| F-test | ** | ** | ** |
| **Genotype** | | | |
| $HD_1$ | $67.1^{e}$ | $93.1^{e}$ | $93.9^{c}$ |
| $HA_9$ | $86.2^{a}$ | $108.3^{b}$ | $110.2^{a}$ |
| $HB_2$ | $75.8^{d}$ | $103.3^{c}$ | $104.6^{b}$ |
| $HB_4$ | $76.1^{d}$ | $98.9^{d}$ | $96.1^{c}$ |
| $HB_6$ | $79.8^{c}$ | $107.8^{b}$ | $109.5^{a}$ |
| $HB_8$ | $85.5^{a}$ | $114.1^{a}$ | $114.4^{a}$ |
| $MD_8$ | $83.5^{b}$ | $113.3^{a}$ | $111.0^{a}$ |
| F-test | ** | ** | ** |
| CV% | 6.29 | 6.26 | 6.7 |

Means in column within each factor designated by the same letter are not statistically different at 0.05 level of probability according to Duncan's Multiple Range Test.

leaves per branch and the leaves were small, having the lowest length and width, while $HD_1$ had the lowest number of total leaves per branch. The heaviest total leaves dry weight was observed with genotype $HB_8$, while genotype $HA_9$ was the lightest total leaves dry weight (Table 7). The longest and broadest leaf dimensions were obtained by genotypes $HB_6$ and $HB_4$ respectively. The genotype $HB_6$ which had the longest leaf length possessed the highest value of leaf length/width ratio, while $HB_4$ which had the broadest leaf width had the lowest value of leaf length/width ratio.

The differences among genotypes for vegetative traits (branches and leaf measurements) could be explained by the natural growth habits and branching of genotypes, concordant with the experience of Botti et al. (1998) and Prat et al. (2008).

***Reproductive parameters***

For this group of parameters, significant differences appeared among genotypes for the two traits (number of flower buds and flowers, and days after October to flowering). Genotype $HB_2$ produced the greater production of flower buds and flowers while $HB_4$ had the lowest production of flower buds and flowers (Table 8). For days after October to flowering genotypes, $MD_8$, $HB_8$, $HB_6$, $HB_4$ and $HD_1$ were considered as early flowering while genotype $HA_9$ was considered as the latest one. Most of the genotypes were flowered at the 1st half of December, while $HB_2$ and $HA_9$ were flowered at the 1st week of January and February, respectively.

Benzioni et al. (1998) studied flowering time for jojoba genotypes and found that, in the 1996 season, clone Q-

**Table 4.** Mean performance of plant height above ground for seven jojoba genotypes from March 1st 2010 to Feb 1st 2011.

| Month | Genotype | | | | | | | CV % |
|---|---|---|---|---|---|---|---|---|
| | $HD_1$ | $HA_9$ | $HB_2$ | $HB_4$ | $HB_6$ | $HB_8$ | $MD_8$ | |
| Mar 1st | $50.2^{d}$ | $64.3^{a}$ | $54.6^{cd}$ | $56.6^{bc}$ | $56.9^{bc}$ | $62.4^{a}$ | $60.7^{ab}$ | 5.8 |
| Apr 1st | $53.0^{c}$ | $68.6^{a}$ | $60.3^{b}$ | $62.5^{ab}$ | $63^{ab}$ | $67.2^{ab}$ | $65.5^{ab}$ | 8.0 |
| May 1st | $55.6^{c}$ | $71.3^{ab}$ | $64.5^{ab}$ | $63.2^{b}$ | $65.1^{ab}$ | $71.6^{ab}$ | $71.0^{ab}$ | 8.7 |
| Jun 1st | $60.3^{d}$ | $76.5^{ab}$ | $70.3^{bc}$ | $67.3^{c}$ | $71.3^{bc}$ | $79.0^{a}$ | $76.6^{ab}$ | 7.3 |
| Jul 1st | $62.9^{c}$ | $80.9^{a}$ | $72.8^{b}$ | $70.9^{b}$ | $72.8^{b}$ | $82.3^{a}$ | $79.6^{a}$ | 6.8 |
| Aug 1st | $65.0^{d}$ | $83.4^{a}$ | $74.6^{bc}$ | $72.5^{c}$ | $76.2^{bc}$ | $83.9^{a}$ | $80.3^{ab}$ | 6.4 |
| Sep 1st | $68.4^{c}$ | $89.0^{a}$ | $78.0^{b}$ | $77.9^{b}$ | $83.5^{ab}$ | $87.7^{a}$ | $85.5^{a}$ | 6.4 |
| Oct 1st | $73.4^{d}$ | $95.2^{a}$ | $84.1^{bc}$ | $82.3^{c}$ | $89.6^{ab}$ | $92.0^{a}$ | $91.1^{a}$ | 5.5 |
| Nov 1st | $77.3^{e}$ | $100.7^{a}$ | $85.5^{d}$ | $86.7^{cd}$ | $93.1^{bc}$ | $96.7^{ab}$ | $95.4^{ab}$ | 5.5 |
| Dec 1st | $78.8^{d}$ | $101.3^{a}$ | $87.4^{c}$ | $89.9^{bc}$ | $94.5^{ab}$ | $100.1^{a}$ | $97.4^{a}$ | 5.6 |
| Jan 1st | $80.1^{d}$ | $101.6^{a}$ | $88.2^{c}$ | $91.2^{bc}$ | $95.3^{ab}$ | $101.5^{a}$ | $98.7^{a}$ | 5.3 |
| Feb 1st | $80.4^{d}$ | $101.7^{a}$ | $88.8^{c}$ | $92.5^{bc}$ | $96.2^{ab}$ | $101.7^{a}$ | $100.3^{a}$ | 5.4 |

Means in each row designated by the same letter are not statistically different at 0.05 level of probability according to Duncan's Multiple Range Test.

**Table 5.** Mean performance of plant diameters (North–South axis and East–West axis) for seven jojoba genotypes from Apr 1st 2010 to Jan 1st 2011.

| Genotype | Apr 1st 2010 | | Jul 1st 2010 | | Oct 1st 2010 | | Jan 1st 2011 | |
|---|---|---|---|---|---|---|---|---|
| | N-S | W-E | N-S | W-E | N-S | W-E | N-S | W-E |
| $HD_1$ | $73.1^{c}$ | $75.0^{b}$ | $86.8^{c}$ | $89.1^{b}$ | $100.7^{c}$ | $101.5^{c}$ | $111.7^{d}$ | $109.9^{d}$ |
| $HA_9$ | $84.8^{a}$ | $85.4^{a}$ | $100.7^{a}$ | $101.4^{a}$ | $118.7^{ab}$ | $123.3^{a}$ | $129.1^{abc}$ | $130.7^{ab}$ |
| $HB_2$ | $82.5^{ab}$ | $83.5^{a}$ | $97.9^{ab}$ | $99.1^{a}$ | $110.7^{b}$ | $113.6^{ab}$ | $122.0^{bc}$ | $122.0^{bc}$ |
| $HB_4$ | $75.5^{bc}$ | $73.0^{b}$ | $89.7^{bc}$ | $86.7^{b}$ | $110.7^{b}$ | $106.6^{bc}$ | $119.5^{cd}$ | $118.1^{cd}$ |
| $HB_6$ | $81.3^{ab}$ | $83.8^{a}$ | $96.5^{ab}$ | $99.5^{a}$ | $121.9^{a}$ | $123.1^{a}$ | $131.3^{abc}$ | $131.6^{ab}$ |
| $HB_8$ | $87.8^{a}$ | $84.7^{a}$ | $104.3^{a}$ | $100.5^{a}$ | $128.2^{a}$ | $124.1^{a}$ | $136.1^{a}$ | $136.1^{ab}$ |
| $MD_8$ | $87.5^{a}$ | $85.8^{a}$ | $103.8^{a}$ | $101.8^{a}$ | $125.5^{a}$ | $124.3^{a}$ | $136.4^{a}$ | $132.1^{a}$ |
| CV% | 6.7 | 7.7 | 6.7 | 7.7 | 6.1 | 6.9 | 5.7 | 5.6 |

Means in column designated by the same letter are not statistically different at $P<0.05$ level according to Duncan's Multiple Range Test.

106 was in full bloom at the end of February and clone 64 was in full bloom in the middle of March. Flowering in 1997 occurred at the beginning of January for clone Q-106 and at the beginning of April for clone 64. These authors concluded that the early genotype, with its low cooling demands, flowered very early, but late genotype, although presumably ready to flower could not reach anthesis till temperatures began to rise.

## Yield parameters

In general, fruit set was very low in the 1st year of seed evaluation for all genotypes except genotype $HA_9$, which did not have any seeds (Table 9). This result might suggest the fact that jojoba plants were still very young (only 1.5 years of age) and the males were small and did not bear many flowers. Significant differences were present among the genotypes in all seed parameters measured, and it corroborates the large amount of variability in jojoba materials. Genotype $HB_8$ recorded the highest values for seed yield plant$^{-1}$ and seed weight with insignificant difference with $MD_8$ genotype. $HB_6$ genotype had the lowest seed weight in most cases (Table 9). Seed weight ranged from 0.57 to 0.80 g in the third season (2012 season). Genotypes $HB_8$ and $MD_8$ had almost similar values in all seed traits; this confirmed the

**Table 6.** Mean performance of branch length (cm), branched nodes, total number of nodes, branch dry weight (g) and internodes length (cm) for seven jojoba genotypes.

| Genotype | Branch length (cm) | Branched nodes | Total number of nodes | Branch dry weight (g) | Internodes length (cm) |
|---|---|---|---|---|---|
| $HD_1$ | $24.4^{cd}$ | $1.06^{c}$ | $13.4^{b}$ | $1.01^{bc}$ | $2.71^{cd}$ |
| $HA_9$ | $23.0^{d}$ | $0.82^{c}$ | $13.7^{b}$ | $0.77^{c}$ | $2.55^{d}$ |
| $HB_2$ | $22.4^{d}$ | $2.68^{a}$ | $23.9^{a}$ | $1.25^{ab}$ | $2.48^{d}$ |
| $HB_4$ | $24.9^{cd}$ | $0.86^{c}$ | $13.8^{b}$ | $1.24^{ab}$ | $2.76^{cd}$ |
| $HB_6$ | $27.1^{bc}$ | $1.02^{c}$ | $15.0^{b}$ | $1.20^{b}$ | $3.01^{bc}$ |
| $HB_8$ | $30.6^{a}$ | $2.34^{a}$ | $21.8^{a}$ | $1.58^{a}$ | $3.39^{a}$ |
| $MD_8$ | $29.1^{ab}$ | $1.66^{b}$ | $17.0^{b}$ | $1.29^{ab}$ | $3.23^{ab}$ |
| F-test | ** | ** | ** | ** | ** |
| CV % | 8.5 | 13.29 | 15.8 | 20.12 | 8.48 |

Means in column designated by the same letter are not statistically different at 0.05 level of probability according to Duncan's Multiple Range Test.

**Table 7.** Mean performance of total leaves number, total leaves dry weight (g), leaf length (cm), leaf width (cm) and L/W cm for seven jojoba genotypes.

| Genotype | Total number of leaves | Total leaves dry weight (g) | Leaf length (cm) | Leaf width (cm) | L/W cm |
|---|---|---|---|---|---|
| $HD_1$ | $26.7^{b}$ | $2.84^{b}$ | $4.03^{bcd}$ | $1.48^{b}$ | $2.73^{b}$ |
| $HA_9$ | $27.4^{b}$ | $2.12^{c}$ | $3.95^{bcd}$ | $1.38^{bc}$ | $2.88^{ab}$ |
| $HB_2$ | $47.7^{a}$ | $3.20^{b}$ | $3.55^{d}$ | $1.20^{c}$ | $2.96^{ab}$ |
| $HB_4$ | $27.5^{b}$ | $2.99^{b}$ | $3.70^{cd}$ | $1.83^{a}$ | $2.03^{c}$ |
| $HB_6$ | $29.9^{b}$ | $3.01^{b}$ | $5.00^{a}$ | $1.55^{b}$ | $3.32^{a}$ |
| $HB_8$ | $43.5^{a}$ | $4.43^{a}$ | $4.25^{bc}$ | $1.48^{ab}$ | $2.90^{ab}$ |
| $MD_8$ | $34.0^{b}$ | $3.32^{b}$ | $4.55^{ab}$ | $1.48^{ab}$ | $3.07^{ab}$ |
| CV % | 15.8 | 15.73 | 11.06 | 10.37 | 13.13 |

Means in column designated by the same letter are not statistically different at P<0.05 level according to Duncan's Multiple Range Test.

**Table 8.** Mean performance of number of flower buds and flowers, number of days after October (DAO) to flowering and flowering date for seven jojoba genotypes.

| Genotype | Number of flower buds and flowers | DAO to flowering (day) | Flowering date |
|---|---|---|---|
| $HD_1$ | $4.24^{cd}$ | $44^{c}$ | Dec 14 |
| $HA_9$ | $4.66^{cd}$ | $95^{a}$ | Feb 3 |
| $HB_2$ | $9.00^{a}$ | $66^{b}$ | Jan 5 |
| $HB_4$ | $4.00^{d}$ | $38^{cd}$ | Dec 8 |
| $HB_6$ | $5.78^{bc}$ | $36^{d}$ | Dec 6 |
| $HB_8$ | $6.84^{b}$ | $35^{d}$ | Dec 5 |
| $MD_8$ | $5.74^{b}$ | $34^{d}$ | Dec 4 |
| CV % | 21.1 | 10.6 | |

Means in column designated by the same letter are not statistically different at P<0.05 level according to Duncan's Multiple Range Test.

**Table 9.** Mean performance of seed yield plant$^{-1}$ and seed weight for seven jojoba genotypes in three seasons.

| Genotype | Seed yield plant$^{-1}$ (g) | | | Seed weight (g) | | |
|---|---|---|---|---|---|---|
| | 2010 season | 2011 season | 2012 season | 2010 season | 2011 season | 2012 season |
| $HD_1$ | $2.33^{bc}$ | $189.3^{b}$ | $493.2^{b}$ | $0.61^{ab}$ | $0.43^{b}$ | $0.70^{ab}$ |
| $HA_9$ | - | $78.7^{c}$ | $335.3^{b}$ | - | $0.32^{c}$ | $0.67^{b}$ |
| $HB_2$ | $3.92^{ab}$ | $220.6^{a}$ | $738.7^{a}$ | $0.70^{a}$ | $0.48^{ab}$ | $0.68^{b}$ |
| $HB_4$ | $3.70^{c}$ | $249.1^{a}$ | $778.4^{a}$ | $0.74^{a}$ | $0.48^{ab}$ | $0.80^{a}$ |
| $HB_6$ | $3.57^{abc}$ | $112.5^{c}$ | $461.6^{b}$ | $0.45^{b}$ | $0.35^{c}$ | $0.57^{c}$ |
| $HB_8$ | $5.08^{a}$ | $262.4^{a}$ | $821.6^{a}$ | $0.74^{a}$ | $0.51^{a}$ | $0.80^{a}$ |
| $MD_8$ | $4.75^{ab}$ | $233.7^{a}$ | $741.7^{a}$ | $0.75^{a}$ | $0.47^{ab}$ | $0.78^{a}$ |
| F-test | ** | ** | ** | ** | ** | ** |

Means in column designated by the same letter are not statistically different at $P<0.05$ level according to Duncan's Multiple Range Test.

**Table 10.** Simple correlation coefficients of various characters among seven jojoba genotypes.

| Characters | Seed yield | Seed weight |
|---|---|---|
| Seed weight | 0.789** | 1.000 |
| Branch length | 0.246 | 0.273 |
| Length of internodes | 0.231 | 0.259 |
| Branched nodes | 0.469** | 0.596** |
| Branch dry weight (g) | 0.156 | 0.169 |
| Total number of nodes | 0.455** | 0.544** |
| Total number of leaves | 0.456** | 0.545** |
| Number of flower buds | 0.328 | 0.465** |
| Number of flower buds and flowers | 0.086 | 0.087 |
| Total leaves dry weight (g) | 0.343* | 0.341* |
| Number of days after Oct. to flowering | -0.493** | -0.461** |
| Plant diameters (North–South axis) | 0.200 | 0.031 |
| Plant diameters (East–West axis) | 0.086 | -0.105 |
| Plant height | 0.067 | -0.080 |

previous finding which indicated that these two genotypes had similar values for most characters. Al-Soqeer et al. (2012), using ISSR primers, noticed that genotypes $HB_8$ and $MD_8$ were found in the same sub-cluster (9.20 and 20.17%, respectively).

These levels of seed yield can be considered very good when they are compared with the results obtained by other researchers. It is evident from these data that clones $HB_8$ offer good production prospects and may be recommended for commercial production in Qassim region. It was noteworthy that Al-Soqeer et al. (2012) reported that $HB_8$ was the lowest in simmondsin in both the seeds and seed meal and recorded the highest oil content (54.4%).

In previous studies, Mckelvie et al. (1994) reported that yields of the new jojoba varieties, planted as cuttings, at an average density of 1250 plants per hectare, will yield at least 0.2 tons of seed per hectare in year 4, gradually increasing to 1.6 tons of seed per hectare by year 12. After year 12, yields are expected to remain fairly constant. Ulger et al. (2002) found in previous studies, seed yield of jojoba plants ranged from 0.02 to 0.5 kg per plant from 4-year-old in Alata, Mersin, Turkey. Dunstone and Begg (1983) indicated that the first significant harvest was possible 4 years after planting with yields of about 100-200 g per female plant. Ayerza (1996) and Benzioni et al. (1996) in Argentina and Israel, respectively, reported yields which fluctuated between 705 and 148 g plant$^{-1}$ in the third year of growth. Osman and AboHassan (2013) reported that average seed yield varied from 0.18

to 0.59 kg plant$^{-1}$ at Hail region in the fourth and fifth year respectively. It was noteworthy that seed yield in our results exceeded the range of seed yield recorded in other regions. Osman and AboHassan (2002) reported that, seed weight for jojoba among the irrigation treatments ranged from 0.85 to 0.95 g and from 0.62 to 0.75 g in the respective years and was not adversely affected by drought stress.

The phenotypic correlations coefficients among different plant characters of seven jojoba genotypes are presented in Table 10. The highly significant positive correlation of seed yield with seed weight, branched nodes, total number of nodes and total number of leaves reveal that selection should be practiced for higher seed weight, branched nodes, total number of nodes and total number of leaves genotypes to select high yielding jojoba genotypes. Meanwhile, highly significant negative correlation of seed yield with number of days after October to flowering reveal that selection should be practiced for early flowering genotypes in isolating high yielding jojoba genotypes. Similar trend was obtained between seed weight and other traits. Benzioni et al. (1999) found that some clones exhibited excellent vegetative traits related to yield potential, such as, rapid growth and extensive branching.

The existence of significant differences among jojoba genotypes for all of the parameters studied indicate that there is a large genetic variability among jojoba genotypes established at Qassim Region, which could permit improvement by selection and breeding. The results also indicate that jojoba can grow very well in the Central Region of Saudi Arabia, and it can be a new source of income for growers. It can also protect the soil against wind erosion. In addition, jojoba plants can be grown well in semiarid regions and it is more suitable in these regions that are considered marginal areas for conventional crops.

## Conclusions

The variations observed in the studied characters were principally due to clone differences. It is concluded that jojoba shows good establishment under Central Region of Saudi Arabia. Genotypes $HA_9$ recorded the highest value for plant height. For number of branches per plant, genotype $HB_2$ had the highest. Clones $HB_8$ and $MD_8$ had almost similar values in most traits. For stem diameter, clone $HB_2$ recorded the highest value. Genotype $HB_6$ recorded the largest leaf area, the heaviest dry leaf and lowest value of specific leaf area. Clone $HB_2$ recorded the lowest and highest values of leaf dry weight and specific leaf area, respectively. Moreover, the genotypes $HB_8$, $MD_8$ and $HD_1$ flowered early. Genotype $HB_8$ recorded the highest values for seed yield plant$^{-1}$ and seed weight with insignificant difference with $MD_8$ genotype, while $HB_6$ had the lowest seed weight. It is evident from these data that clone $HB_8$ offers good production prospects and may be recommended for commercial production in Qassim region. The results obtained in this work indicate that there is a large genetic variability among jojoba clones established at Qassim Region, which could permit improvement by selection and breeding.

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