BOOK OF PROCEEDINGS

VII International Scientific Agriculture Symposium
Jahorina, October 06-09, 2016

agrosym
2016
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VII International Scientific Agriculture Symposium
“Agrosym 2016”

AGROSYM 2016

Jahorina, October 06 - 09, 2016
Impressum
VII International Scientific Agriculture Symposium „Agrosym 2016“

Book of Proceedings
Published by
University of East Sarajevo, Faculty of Agriculture, Republic of Srpska, Bosnia
University of Belgrade, Faculty of Agriculture, Serbia
Mediterranean Agronomic Institute of Bari (CIHEAM - IAMB) Italy
International Society of Environment and Rural Development, Japan
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Institute of Field and Vegetable Crops, Serbia
Institute of Forestry, Podgorica, Montenegro
Balkan Scientific Association of Agricultural Economics, Serbia
Institute of Agricultural Economics, Serbia

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Website:
http://www.agrosym.rs.ba

CIP - Каталогизација у публикацији
Народна и универзитетска библиотека
Републике Српске, Бања Лука

631(082)(0.034.2)
INTERNATIONAL Scientific Agricultural Symposium "Agrosym 2016" (7 ; Jahorina)
CD ROM čitač. - Nasl. sa nasl. ekrana. - Registar.
ISBN 978-99976-632-7-6
COBISS.RS-ID 6216984
INFLUENCE OF TEMPERATURE, PRECIPITATION AND INSOLATION ON THE DEVELOPMENT RATE OF ANNUAL CARAWAY (Carum carvi var. annua)

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Abstract

Caraway (Carum carvi L.) is a plant from the Apiaceae family (Umbelliferae). It has two forms: annual (C. carvi var. annua), which usually grows in warm climates, and biennial (C. carvi var. biennis), which grows in cooler climates. However, introducing the annual caraway to agroecological conditions of Serbia has the purpose of shortening the production cycle of this plant as the biennial variety is not profitable during the first year, requires significant investment and occupies space. The purpose of this research was to determine the duration of the vegetation period, the requirements for temperature, moisture and insolation of annual caraway during the phenological stages. The experiment was conducted during two years at three locations in Vojvodina Province. The sowing-harvest period of annual caraway lasts from 136-177 days, requires above 3000 degree days, whereas the amount of precipitation needs to be a minimum of 200 mm, and number of sunshine hours between 1250 and 1480. There is a strong relationship between temperature, precipitation and insolation that influences the development rate during the caraway vegetation period.

Keywords: caraway, production cycle, temperature, moisture, insolation

Introduction

Caraway (Carum carvi L.) is a plant from the Apiaceae family (Umbelliferae). It has two forms: annual (C. carvi var. annua), which usually grows in warm climates, and biennial (C. carvi var. biennis), which grows in cooler climates. However, both forms have the tap root system, white or pale yellow, 15–20 cm long and 1–2 cm thick. Caraway germinates with two lanceolate descending cotyledons, while the first true leaf is feathery and unequally divided. The leaves of the leaf rosette and lower leaves are on long petioles, with 6–12 lobes that are double or triple pinnate. The leaves on the stem are arranged alternately, and the leaves at the top are thread-like. Biennial caraway forms only the leaf rosette in the first year, which consists of 7–18 leaves usually up to 20 cm long. With the end of the vegetation period the above-ground part dies, while the root winters. In the spring, the development of the plant starts early, and 4–5 weeks after the first shoots appear, a flower stem develops. The vegetation period of this form of caraway usually lasts 440–460 days. In contrast, annual caraway forms a leaf rosette with fewer leaves (usually up to five), and the umbel quickly starts developing. The vegetation period lasts 140–160 days. The flower stem is upright with a branching upper part, each branch ends in an umbel, which consists of 5 to 16 primary rays – umbelletes. The flowers consist of five petals which are white or pale pink with tips bent upward (Aćimović 2016).
Caraway fruit (*Carvi fructus*) is a schizocarp, a seed (reproductive plant organ) and drug (medicinal raw material) as well as spice at the same time. The fruit is gray brown in color, 3–7 mm long, 1–1.25 mm wide, with a crescent curve. Usually, a schizocarp separates spontaneously into two mericarps. Each mericarp has nine longitudinal ridges, between which are the channels with essential oil. Caraway fruit contain from 1 to 6% of essential oil (*Carvi aetheroleum*) that gives caraway its characteristic aroma (Sedláková et al. 2003). There are approximately 30 compounds in caraway essential oil, among which carvone and limonene account for about 95%. Other components are present in small proportions (Bouwmeester et al. 1995). These two components have a wide range of applications. The biennial caraway is usually grown in our region, because it has higher seed yield and essential oil content. However, introducing annual caraway to the agroecological conditions of Serbia has the purpose of shortening the production cycle of this plant as the biennial variety is not profitable during the first year, requires significant investment and occupies space. The purpose of this research was to determine the duration of the vegetation period, the association of annual caraway productivity with temperature, moisture and insolation during the phenological stages.

**Material and methods**

The seed used in this study was an annual local ecotype of caraway seed. The field experiment was carried out during 2011 and 2012 at three localities in Vojvodina Province, Serbia: Mošorin (latitude 45°18'5''N; longitude 20°09'32''E), Veliki Radinci (latitude 45°02'26''N; longitude 19°40'15''E) and Ostojićevo (latitude 45°53'16''N; longitude 20°09'31''E).

The climate in Vojvodina Province is moderate continental with some tendencies towards continental. The whole region is located in a semi-arid area where variations in the amount of precipitation, air temperature and other important climatic elements are substantial over the years. The weather conditions in 2011 and 2012 indicate that they were moderately (2011) to severely dry (2012) in during the active growing season (April–September), in relation to long-term averages. Temperature conditions during both years, at the three localities, were similar, but there were significant variations in the amount and distribution of rainfall between the locations and years. Meteorological data were obtained from the meteorological stations nearest to the experimental fields, and are shown in Figure 1.
Caraway seed was sown in the first decade of April (optimal time in Serbian agroecological conditions), with row spacing of 0.35 m, and density of 200 plants/m². The size of the experimental plots was 5 m². Weeds were controlled by hoeing and weeding when needed. Measures of protection from diseases and insects were not used. Harvest was carried out by hand in the phase of full maturity. In 2011, the harvest was performed in the middle of September, and in 2012 because of water deficit and high temperatures the vegetation period was shortened and the harvest was performed in the last decade of August.

The development of the caraway plant was checked daily. Four phenological stages were determined: (1) germination, (2) stem elongation, (3) flowering and (4) fruit formation and maturation. The exact occurrence of these stages was registered both years at the three localities. The duration of each phenological stage was measured in days. Optimum parameters necessary for the cultivation of annual caraway were obtained by comparing the duration of each stage with the sum of effective temperatures (GDD) which present a sum of average daily temperatures above 5 °C, sum of precipitation and insolation.

**Results and discussion**

The growth and development of an annual caraway plant is shown in Figure 2, while the duration of phenological stages in both experimental years in three experimental fields is shown in Figure 3. The vegetation period of annual caraway lasted from 136 to 177 d. It lasted longer in 2011 (an average of 169.0 d) than in 2012 (140.7 d). The germination period lasted 14–19 d, and the period from germination to stem elongation, i.e. leaf rosette formation, was the longest (between 40 and 51 d). Caraway needed 16–27 d from the start of stem elongation to flowering. Flowering lasted 15–29 d, and fruit formation and maturation 40–51 d. All phenological stages during 2012 were shorter on average by 5.7 d compared with 2011, which in the end resulted in the shortening of the total vegetation period by 28.3 d.
Figure 2. Growth and development of *Carum carvi* var. *annua*

Figure 3. Duration of phenological stages of annual caraway during 2011 and 2012 at three localities (S—sowing, G—germination, SE—stem elongation, F—flowering, FF—fruit formation and maturation, H—harvest).

The GDD during phenological stages of annual caraway in both years is shown in Figure 4. In 2011, which was more favorable for caraway yield formation, the average sum of effective temperatures was 3207 °C (3048–3317 °C). During 2012, the sum of effective temperatures was lower by 13.2% and the average was 2783 °C (2693–2960 °C). During the period from sowing to germination, the sum of effective temperatures was 170 °C (in 2011), and 179 °C (in 2012). For the period from forming a leaf rosette until maturation, the sum of temperatures was lower in 2012 in comparison with 2011. In 2012, during the period of leaf rosette formation, a sum of effective temperatures lower by 63 °C was recorded when compared with the previous year. During the period of flowering, this difference was 83 °C, in the period of fruit formation 212 °C, and during maturation 75 °C. However, during the second year, the mean daily temperatures were higher on average by 1.2 °C. Higher average daily temperatures could have caused shortening of the caraway vegetation period in the second year of the study.
Precipitation during the vegetation period in 2011 was 20% higher on average than in 2012. Also, the precipitation in the first year was better distributed during the vegetation period. However, the lowest precipitation was noted from sowing to germination. Nevertheless, the seed used moisture reserves from the winter period, so this deficit had no negative influence on germination. During the rest of the 2011 growing season, rainfall was evenly distributed and sufficient for the formation of high yield.

In 2012, in the period from sowing to germination there was enough rainfall (34–50 mm) which enabled uniform and fast germination of caraway seed. Also, during the period of leaf rosette formation (from germination to stem elongation) the quantity of rainfall was optimal. However, in the period from stem elongation until flowering, there was a significant rainfall deficit. The dry period continued during the stage of fruit formation, which had a negative impact on the thousand fruit mass and germinability. In the period of fruit maturation there was an average of 47 mm of rainfall, but it had no effect on the increase of fruit yield. Thus, drought in the generative stages had a negative effect on the caraway fruit yield formation.

The influence of insolation on the duration of the caraway vegetation period and some phenological stages are shown in Figure 5. During the caraway vegetation period in 2011, the average duration of insolation was 1442 h. In 2012, the average number of sunshine hours was lower by 117, amounting to 1325 h. Compared with 2011, in 2012, a higher number of sunshine hours was recorded only in the period of leaf rosette formation. In all other phenological stages, the amount of insolation was smaller in the second year.
Weather conditions influenced qualitative parameters of caraway fruits such as essential oil content, oil component ratios, thousand fruit mass, and seed germination (Aćimović et al. 2014; Aćimović et al. 2015). Weather conditions also influenced morphological parameters such as plant height, umbel diameter, number of umbels per plant, as well as whole plant mass, yield of fruits per plant, and harvest index.

Fruit yield per plant was strongly influenced by weather conditions in 2011 and 2012 (Table 1). In the favorable year (2011), the yield of fruits per plant was 4.25 g, while in the dry year (2012) it was significantly lower (only 0.96 g). The yield of fruits per plant is determined by the number of umbels per plant, number of fruits per umbel and thousand fruit mass. All these parameters were significant higher in 2011 than in 2012.

During a dry year in Hungary, the yield of annual caraway fruit per plant was very low, ranging between 0.02‒0.82 g, while in moderate drought conditions it was slightly higher, reaching 1.73 g (Valkovszki 2011). In Tunisia the yield of fruit per plant was between 0.70‒1.33 g, while in Lithuania it was 1.1‒2.9 g (Laribi et al. 2010; Petraityte 2005).

Whole plant mass was also significantly influenced by weather conditions (Table 1). In the favorable year, across the three trial locations average mass per plant was 10.02 g, while in the dry year it was only 4.21 g, a reduction of 58%. In a study by Laribi et al. (2010), whole plant mass was reduced by 20 to 40%, depending on the drought level. These results demonstrate that water deficit is a factor limiting the growth and development of caraway.

Harvest index shows the division of photosynthesis products between fruits and vegetative parts of a plant. In 2011 harvest index was 43.16%, but only 22.65% in 2012.

<table>
<thead>
<tr>
<th></th>
<th>Fruit mass per plant (g)</th>
<th>Whole plant mass (g)</th>
<th>Harvest index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>4.25±1.02</td>
<td>10.02±2.58</td>
<td>43.16±1.09</td>
</tr>
<tr>
<td>2012</td>
<td>0.96±0.47</td>
<td>4.21±1.89</td>
<td>22.65±2.07</td>
</tr>
<tr>
<td>Average</td>
<td>2.61</td>
<td>7.12</td>
<td>32.91</td>
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</tbody>
</table>
Conclusion

There is a strong relationship between temperature, precipitation and insolation that influences development rate during the caraway vegetation period. However, these parameters primarily affected harvest index, as well as yield of caraway fruit.

References


