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Influence of increased temperature on the yield and quality of broad bean in semiarid regions of northwest China

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ABSTRACT

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In this study, a simulation experiment by farm warming with infrared ray radiator was carried out, and results showed that the broad bean (*Vicia faba* L.) growing days were shortened by increased temperature. The seedling, ramifying, budding, blooming, podding, and maturing stages were shortened by 1–4, 1–2, 1, 2–3, 1–2, and 2–4 days, respectively, and the whole growing period was shortened by 7–16 days when the temperature increased by 0.5–2.0°C. The broad bean yield increased by 10.1–16.6% when the temperature increased by 0.5–1.0°C, and significantly decreased by 38.1–90.1% when the temperature increased by 1.5–2.0°C. Increased temperature significantly improved the fat, carbohydrate, ash and energy contents.

Keywords: global warming; period of increased temperature; growth stages of broad bean; agricultural production; food security

The 5[th] Evaluation Report of the IPCC (IPCC 2016) showed that there was a clear human activity impact on the climate system, and that this impact was increasing. Furthermore, different types of impact were detected on each continent. Since 1950, many climate changes, unprecedented over the past hundreds or even thousands of years, have been detected. There is no doubt that the global climate system is warming in almost all areas of the world. The 3[rd] Climate Change Evaluation Report for China suggested that the temperature in China will rise by 1.3–5.0°C by the end of this century (Shen and Wang 2013). In comparison, the global mean level will increase 1.0–3.7°C (Qing and Thomas 2014).

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Over the past 50 years, the temperature in the semiarid district of northwest China has increased, rainfall has declined, and the climate has become significantly drier and warmer (Zhang et al. 2010). Climate seriously impacts food safety when there are increases in temperature, aridity, and warm winters. Climate warming also modifies the absorption of trace and heavy metal elements and causes a lack of nutrients and excessive uptake of toxic elements, such as Al and Mn (Li et al. 2012). This decreases the distributed proportions of photosynthetic products in stems, leaves and fruits and directly reduces food nutritional value (Lu et al. 2015). It is predicted that the global climate will continue to warm over the next 50 years, and this will directly impact agriculture and bring new challenges to food safety (Huang et al. 2013).

Continuous cropping or intercropping of bean crops and gramineous crops is the major cropping mode in the semiarid regions of northwest China. Broad bean (*Vicia faba* L.) is a major bean crop that is widely planted in the semiarid regions of northwest China. It has a series of outstanding biological and agricultural characteristics that have enabled it to adapt to the environment. Therefore, it is necessary to carry out the study of the impact of warming on broad bean. The study found that broad bean water use efficiency increased and then decreased with temperature rising. The water use efficiency increased when the temperature was increased by 0.5–1.0°C, and it quickly decreased when the temperature was increased by 1.5–2.0°C (Xiao et al. 2016). In paper, a simulation experiment by farm warming with infrared ray radiator was used to study the impact of increased temperature on broad bean growth, yield and quality. The results should provide a scientific basis for improving broad bean adaptability to climate change in the semiarid regions of northwest China.

MATERIAL AND METHODS

The research area. The research base was at the Guyuan Agricultural Meteorology Experiment Station (36°02'N, 106°28'E), which is located in a semiarid region of northwest China, 1879.7 m a.s.l. Between 1959 and 2015, the annual mean temperature was 6.3–10.2°C, and the temperature has significantly increased since 1998 (Figure 1). The major crops are wheat, corn, broad bean and potato, which mature once a year. The area is a typical semiarid rainfed agricultural area on the Loess Plateau.

Simulated farm-increased temperature test. A simulation experiment by farm warming with infrared ray radiator was used to study the impact of warming on broad bean yield and quality. The Climate Change Conference held by the UN in Copenhagen in December 2009 stated that global warming over the next 50 years should be controlled within 2.0°C (Zheng 2010). Therefore, this research used five warming levels, which were 0, 0.5, 1.0, 1.5, and 2.0°C under simulation experiment with farm warming. Each test plot was 8 m^2 (2 × 4 m), plots were spaced 3.0 m apart and replicated in three randomized complete blocks. Each plot was equipped with infrared radiator warming tubes and the support height was adjusted so that the warming tube was 1.2 m from the crop canopy. The power of the infrared radiator warming tube

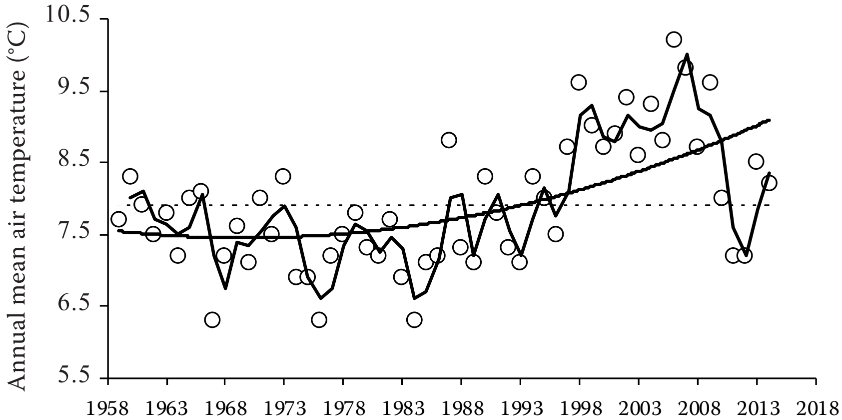

Figure 1. Air temperature change in the semiarid Guyuan area during 1960–2014. Annual mean air temperature data for the semiarid area of Guyuan between 1959 and 2014 were acquired from the China meteorological administration

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was fixed according to the warming treatment and local weather. The power ratings of the infrared radiator warming tubes were 0, 250, 500, 750, or 1000 W, respectively. The broad beans were warmed from broad bean sowing to harvesting stage.

The broad beans were sown manually on April 20, from 2014 to 2016. A sowing density of 180 kg seed/ha was used. The cultivar selected was Qingchan 3, which has a milk white seed coat and is the recommended cultivar for the local district (Li and An 2005). The broad beans were harvested on July 10, 2014, July 18, 2015, and July 15, 2016. The soil in the experiment farm is a Loess soil, which is deep and can be easily ploughed. The farm was surrounded by a fence to prevent animal damage. The organic matter in the soil was 8.3 g/kg, total nitrogen 0.44 g/kg, total phosphorus 0.68 g/kg, and total potassium 19.1 g/kg.

Measurement methodology and monitoring. The days taken up by the seedling stage, ramifying stage, budding stage, blooming stage, podding stage and maturing stage, as well as the whole growing period, were recorded. The plant density, number of pods per plant, number of grains per pod, hundred-grain weight and yield were also recorded, and the fat, protein, carbohydrate, ash and energy contents of the seeds were measured.

The fat, protein, carbohydrate, ash, and energy, contents were measured according to the national food safety standards. All samples were fresh and measured within 1 week. During the warming period, each plot was equipped with an automatic temperature sensor (USA) to monitor the temperatures at 10, 20, and 30 cm from the ground or canopy, the data were recorded once every 20 min and saved in the recorder (Campbell AR5, USA; ± 0.1°C). The correlations on broad bean yield and quality were processed and charted by the analysis software of IBM SPSS Statistics 18.0 (Zhang 2006).

RESULTS AND DISCUSSION

Impact of increased temperature on the growth stages of broad bean. It is known that temperature influences evapotranspiration by affecting leaf stomatal conductance, and high temperatures can reduce the activity of photosynthetic enzymes, destroy chloroplast structure, and shut the air pores, all of which reduce photosynthesis. The enhanced respiration intensity of a crop subjected to higher temperatures will increase consumption and reduce net accumulation by photosynthesis (Shen et al. 2002, Reichstein et al. 2002, Zhao et al. 2007).

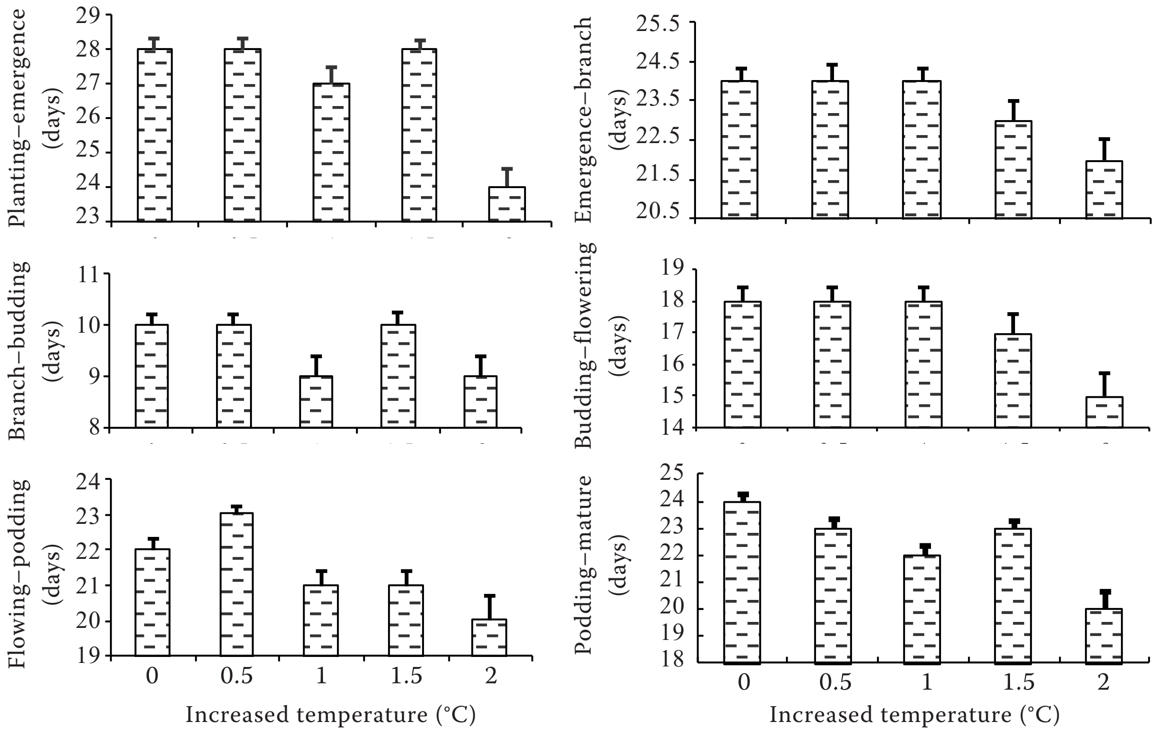

Figure 2. Impact of increased temperature on the number of days from sowing to the seedling stage of broad bean

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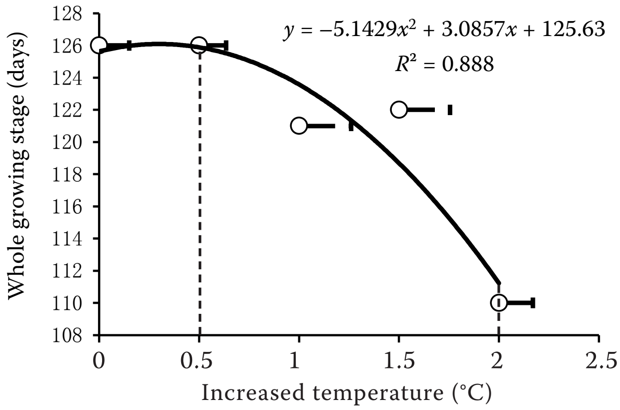

Figure 3. Impact of increased temperature on the whole growing stage of broad bean

Increased temperature significantly affects plant growth by evapotranspiration. Increased temperature will significantly influence growth of broad bean in the semiarid regions of China. The correlation between increased temperature and the lengths of different growing stages of broad bean, days from sowing to seedling, seedling–ramifying, ramifying–budding, budding–blooming, blooming–podding, podding–maturing, all changed with increased temperature. When the temperature was increased by 0.5–2.0°C, the broad bean seedling stage, ramifying stage, budding stage, blooming stage, podding stage and maturing stage were shortened by 1–4, 1–2, 1, 2–3, 1–2, and 2–4 days, respectively (Figure 2). The correlation between increased temperature and the length of the whole growing period suggested that the length was shortened by increased temperature. The whole growing period was shortened by 7–16 days, when the temperature was increased by 0.5–2.0°C (Figure 3). The correlation between the broad bean whole growing period (Y) and increased temperature can be expressed as $Y = -5.1429X^2 + 3.0857X + 125.63$ ($R^2 = 0.888$), and shows that the whole growing period will be shortened and that broad bean growth will be affected by increased temperature.

Increased temperature causes the sowing stage of spring-sown crops to advance, and the whole growth period to change in the semiarid regions of China (Xiao et al. 2013). Over the last 20 years, the whole spring wheat growth period has been shortened

Table 1. Impact of increased temperature on broad bean yield and yield composition

Year	Increased temperature (°C)	Harvested plants (100 000/ha)	Pods per plant	Grains per pod	Grains per plant	Hundred-grain weight (g)	Yield (t/ha)	Yield increased (decreased) (%)
2014	0	6.17[a]	5.6[a]	7.4[a]	41.8[a]	160.0[a]	3702.0[a]	–
	0.5	6.19[a]	5.8[a]	8.5[a]	49.3[b]	160.8[a]	4183.3[b]	+13.0
	1.0	6.18[a]	6.2[b]	8.4[a]	51.1[c]	168.2[a]	4317.6[b]	+16.6
	1.5	6.19[a]	4.4[b]	6.3[a]	27.1[b]	162.3[a]	2213.0[b]	–40.2
	2.0	6.17[a]	4.1[b]	5.9[b]	22.9[b]	152.5[b]	1987.0[b]	–86.3
2015	0	6.18[a]	5.7[a]	7.3[a]	40.8[a]	163.0[a]	3905.0[a]	–
	0.5	6.19[a]	5.9[a]	8.5[a]	49.3[b]	160.8[a]	4298.6[b]	+10.1
	1.0	6.19[a]	6.2[b]	8.3[a]	53.2[c]	162.4[a]	4516.5[b]	+15.6
	1.5	6.18[a]	4.3[b]	6.3[a]	27.1[b]	162.6[a]	2414.0[b]	–38.1
	2.0	6.19[a]	4.1[b]	5.7[b]	23.8[b]	150.7[b]	2068.0[b]	–88.8
2016	0	6.18[a]	5.5[a]	7.2[a]	39.8[a]	166.0[a]	3805.0[a]	–
	0.5	6.18[a]	5.7[a]	8.5[a]	49.3[b]	160.9[a]	4397.5[b]	+15.6
	1.0	6.19[a]	6.1[b]	8.5[a]	52.0[c]	165.4[a]	4516.4[b]	+16.1
	1.5	6.18[a]	4.2[b]	6.3[a]	27.1[b]	162.0[a]	2895.1[b]	–39.3
	2.0	6.19[a]	4.1[b]	5.8[b]	24.7[b]	154.6[b]	2001.2[b]	–90.1
Average	0	6.18[a]	5.6[a]	7.3[a]	40.8[a]	163.0[a]	3804.0[a]	–
	0.5	6.19[a]	5.8[a]	8.5[a]	49.3[b]	160.8[a]	4297.5[b]	+12.9
	1.0	6.19[a]	6.2[b]	8.4[a]	52.1[c]	165.3[a]	4417.5[b]	+16.1
	1.5	6.19[a]	4.3[b]	6.3[a]	27.1[b]	162.3[a]	2314.0[b]	–39.2
	2.0	6.19[a]	4.1[b]	5.8[b]	23.8[b]	152.6[b]	2019.0[b]	–88.4

[a,b]Different letters in each column mean a significant difference at $P \leq 0.05$

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by 8–12 days (Zhang et al. 2008), the whole growing period of peas has been shortened by 10–14 days (Xiao et al. 2009). The potato inflorescence forming stage has advanced by 8–9 days, the blooming stage has advanced by 4–5 days, and the growing stage has been prolonged (Yao et al. 2013). The corn nutritional growth stage has advanced by 4–5 days, the reproductive growing stage has advanced by 6–7 days, and the whole growth period has been shortened by 6 days (Li et al. 2014). The winter wheat nutrition growth stage has advanced by 4–7 days, the reproductive growth stage has advanced by 5 days, and the whole growing period has been shortened by 6–9 days (Yao et al. 2013).

Impact of increased temperature on yield. The broad bean yield is determined by the number of plants harvested, the number of grains per plant, and the hundred-grain weight. Table 1 shows that the number of pods per plant, the number of grains per pod, and the number of grains per plant were significantly affected by increased temperature. The number of grains per plant and the hundred-grain weight were significantly increased by increased temperature, but when the temperature increased by 1.0°C or above, they significantly decreased, and, as a result, yield fell sharply. The broad bean yield significantly increased by 10.1–16.6% when the temperature increased by 0.5–1.0°C. However, the yield significantly decreased by 38.1–90.1% when the temperature increase was between 1.5°C and 2.0°C.

Simulated warming reduces the number of spring wheat grains per ear and the hundred-grain weight. When the temperature rises by 1.0–2.5°C, the number of grains per ear of spring wheat decreases by 1–5 grains, and the hundred-grain weight falls by 1.3–8.8 g (Xiao et al. 2009). Warming significantly decreases the number of potatoes per plant, improves the weight of a single potato, and generally increases the yield (Deng et al. 2010).

Impact of increased temperature on quality. It is well known that warming within a suitable range is good for crop photosynthesis and growth. However, excessive warming decreases photosynthesis, enhances transpiration and soil moisture evaporation, inhibits crop growth, and reduces crop quality. Climate warming can either inhibit or promote crop photosynthesis, and dry matter accumulation, and can reduce grain quality. Potato is a crop that grows favourably in cool environments, and low temperature is good for stem tuber dry matter formation and accumulation. Long term high temperatures will increase the number of small tubers per plant, decrease the single tuber weight, inhibit the transfer of

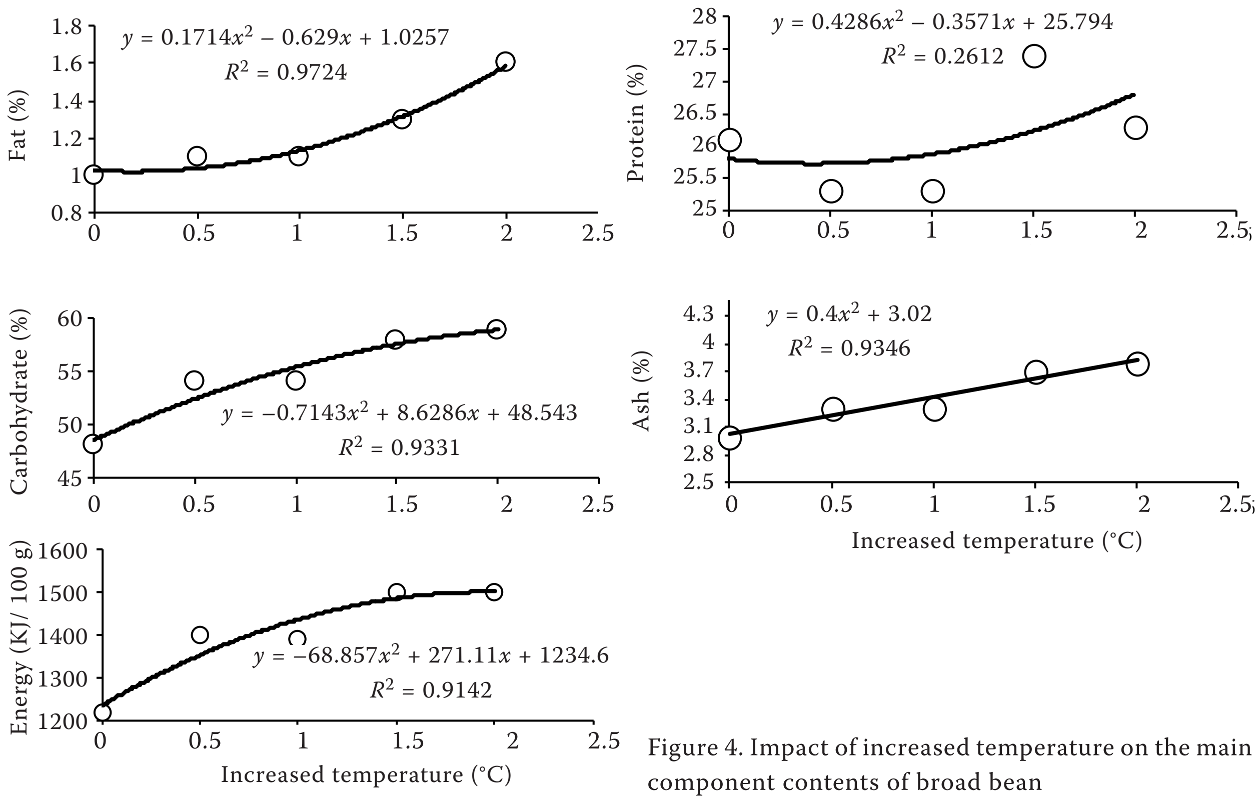

Figure 4. Impact of increased temperature on the main component contents of broad bean

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dry matter into tubers, and affect tuber quality (Li and An 2005).

Broad bean quality is mainly determined by the content of fat, protein, carbohydrate, ash and energy. Figure 4 shows that warming significantly increased the broad bean fat, carbohydrate, ash and energy contents. The correlation between the broad bean fat content (Y) and increased temperature (X) can be expressed by $Y = 0.1714X^2 - 0.0629X + 1.0257$ ($R^2 = 0.9724$), between carbohydrate content (Y) and increased temperature (X) by $Y = -1.7143X^2 + 8.6286X + 48.543$ ($R^2 = 0.9331$), between ash content (Y) and increased temperature (X) by $Y = 0.4X +3.02$ ($R^2 = 0.9346$), and between energy (Y) and increased temperature (X) by $Y = -68.857X^2 + 271.11X + 1234.6$ ($R^2 = 0.9142$). However, the effect of increased temperature on broad bean protein was not significant, and the correlation between protein content (Y) and increased temperature (X) can be expressed by $Y = 0.4286X^2 - 0.3571X + 25.794$ ($R^2 = 0.2612$).

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