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Influence of leaf and silique photosynthesis on seeds yield and seeds oil quality of oilseed rape (*Brassica napus* L.)

Chunli Wang[a,*], Jiangbo Hai[b,1], Jianli Yang[a], Jianhua Tian[a], Wenjie Chen[a], Ting Chen[b], Hongbo Luo[b], Hao Wang[a]

[a] *Hybrid Rapeseed Research Center of Shaanxi Province, Yangling, Shaanxi 712100, PR China*
[b] *College of Agronomy, Northwest A&F University, Yangling, Shaanxi 712100, PR China*

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A B S T R A C T

With the purpose of enhancing oil production, the present work was carried out to elucidate relationships between photosynthesis of leaves, siliques and seeds yield and seeds oil accumulation of oilseed rape. Field trials, in which two repeated experiments was carried out during 2012–2014 growth season, a rape hybrids the "Qin You No.7" (*Brassica napus* L.) variety was taken into account. The results showed that, on rape plant the photosynthetic capacity and chlorophyll a, b, carotenoid contents of leaf were significantly higher than that of silique shell. Oil content of 94.7% was achieved in young seeds (sampled at 25th day after flowering ending stage of the tested rape plant) versus to mature seeds, saturated fatty acids percent was higher whereas oleic acid percent was lower of oil extracted from young seeds. During flowering period of the rape plants tested, area and dry weight of leaves attained maximum, treatments of removing leaves induced reduction in seeds number per silique, siliques number, seeds yield per plant and seeds oil content, these indexes were respectively decreased by 73.6%, 43.4%, 83.4% and 10.5% in maximum, and seeds oil composition was not significantly influenced; during seeds growing period of the tested plants, surface area and dry weight of siliques attained maximum, under shading siliques treatment, the 1000-seed weight, seeds yield per plant and seeds oil content were respectively reduced by 57.5%, 61.4% and 44.7% in maximum, and seeds oil oleic acid (C18:1) and linolenic acid (C18:3) percent was decreased, linolic acid (C18:2) and erucidic acid (C22:1) percent was increased. So for oilseed rape plant during flowering period, surface area and photosynthesis of leaves dramatically influenced siliques number, seeds number and seeds yield; while in seeds growth period, surface area and photosynthesis of siliques greatly influenced 1000-seed yield, seeds yield, seeds oil content and oil composition; oil accumulation in rape seeds initiated early since seeds commencing growth, seed mature degree influenced oil composition of seeds.

1. Introduction

Oilseed rape (*Brassica napus* L.) is an important oil crop species widely cultivated in many parts of the world, oil of the plant seeds is mainly consumed in healthy diet, partly used as high quality lubricating oil (Sulek et al., 2010). Moreover, the rape oil is a potential material in synthesizing biodiesel, the biodiesel transformed from rape seeds oil could be utilized in manufactory to depress dramatically increasing in consumption of ultra low sulphur diesel, on a basis of equivalent net energy content; by this way, the energy requirement and global warming potential would be alleviated (Stephenson et al., 2008). As demands for seeds oil of rape plant rapidly enlarged in recent years, works studying to greatly enhance the seeds yield and seeds oil production become increasingly important and urgent.

To oilseeds rape single plant the siliques number is decidable in deciding seeds yield, however the siliques number was determined by survival of branches, siliques, flowers and young pods, rather than by potential number of flowers and pods, ultimately the seed yield was regulated by assimilate availability or photosynthetic matter produced by aboveground part of rape plant during reproduction period (Diepenbrock, 2000; Wang et al., 2011; Habekotté, 1997). General 90–95% of the seeds weight was converted from photosynthetic production. The CO_2-assimilation of rape plant was

* Corresponding author. Fax: +86 029 68259000.
E-mail address: chliwang262@163.com (C. Wang).
[1] Co-first author.

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mainly by stem and leaves during flowering period, during post-flowering period mainly by green silique (Diepenbrock, 2000).

Seeds oil of rape plant contained above 90% triacylglycerol, the triacylglycerol is synthesized in eukaryote cell mainly by two approaches, the first way of conveying diacylglycerol into triacylglycerol by acyl-CoA (acyl-donator), and another way of transferring acyl from phosphatide (donator) to diacylglycerol (receptor) and diacylglycerol by diacylglycerol acyltransferase, the latter is a acyl-CoA independent way. Previous literatures reported that contents of oleic, linoleic and linolenic acids in seeds of oilseed rape (*B. napus*) were heritable stably (Kondra and Thomas, 1978), oilseed rape (*B. napus* L.) pollen with haploid genes was capable in transcribing its DNA into mRNA, and further to activate relative enzymes of synthesizing lipids (Evans et al., 1988). However, many internal and external factors, such as Temperature, ABA, climate seasonal changes and others, together influenced the lipid metabolism in plant (Portarena et al., 2015; Wilmer et al., 1995, 1997). For example, colonization of the arbuscular mycorrhizal fungus *Glomus* sp. to olive trees resulted beneficial effects on photosynthesis, and led in accumulation of unsaturated fatty acids in leaf (Mechri et al., 2014); long-term salinity stress induced oil profiles shift toward long-chain and mono-saturated fatty acids in leaf of *A. annua* L. (Qureshi et al., 2013); when canola exposed to salt stress, linolenic acid percentage increased (Bybordi, 2012).

Rape plant during growth period from initiating flowering to seed mature, dry matter production, seeds setting and oil accumulation were seriously influenced by in- and external conditions, such as light reflection, light absorption of leaves and flower layer, light-use efficiency of green canopy, dry matter partitioning to seeds, and so no. According to indices estimated from canopy area, Müller et al. (2006) derived a sigmoid growth equation to calculate seed yield of winter oilseed rape. With purpose of enhanced seeds yield, oil yield and oil quality, basing on material of the "Qin You No.7" (*B. napus* L.) variety, objective of this paper is to elucidate influences of leaves, silique photosynthesis on seeds yield, seeds oil accumulation and oil composition of oilseed rape plant during reproduction growth period.

2. Material and methods

2.1. Plant material

Plant material of the "Qin-You No.7" (*B. napus* L.) rape variety is a semi winter hybrid, its seeds was supplied by the Hybrid Rapeseed Research Center of Shaanxi Province in China. The variety was planted in large area of the Huang-huai Regional and middle, lower reaches of the Yangtze River in China. Basing results tested by the Quality Inspection Center of the Ministry of Agriculture in China, the variety oil content of seeds was 43.22%, erucic acid and glucosinolate percent of seeds respectively was 0.35%, 22.57 μmol/g.

The present experiment were carried out in two consecutive growing seasons (during years 2012–2014), experiment plots located in a test field of the Hybrid Rapeseed Research Center of Shaanxi Province, China. The field location (108°24′E, 34°20′N, 521 m above sea level) is within semi humid warm temperate zone with continental monsoon climate, the mean of annual rainfall for many years is 650 mm. The annual mean temperature is 13.8 °C (from 1995 to 2012). Soils of the field is attributed to Eum-Orthic Anthrosols of sub-humid area, loamy soil, and the soil physic-chemical characteristics (average) were as follows: organic carbon 8.14 g kg^{-1}, total nitrogen 0.95 g kg^{-1}, total phosphorus 0.83 g kg^{-1}, total potassium 20.42 g kg^{-1}, available phosphorus and exchangeable potassium was 0.021, 0.29 g kg^{-1} respectively.

Plants of the 2012–2013 experiment were sown on 20 September 2012, which initial flowering stage, ending flowering stage respectively was on 23 March, 12 April 2013, and were harvested on 22 May of 2013. The 2013–2014 experiment was sown on 18 September 2013, the plants initial flowering stage, flowering ending stage respectively was on 27 March, 17 April 2014, and were harvested on 2 June of 2014. Also plants for measuring growth indexes were sown on 18 September 2013 and were investigated later.

All seeds of the tested plant were sown in plots field with 0.4 m row wide and 0.3 m plant spacing in a row. When two or three leaves had expanded, the plants were hand-thinned to obtain a uniform plant population of 83,300 h m^{-2}. Normal farming managements were applied in cultivating the plantlets, all plots in the experiment received the same amount of fertilization: during sowing 187.5 kg ha^{-1} of ammonium bi-phosphate ($NH_4H_2PO_4$), 150 kg ha^{-1} of urea and 7.5 kg ha^{-1} borate fertilizer (11.3% of boron content) were applied. All the plots were winter irrigated in December.

2.2. Treatments

At initial flowering stage, individual plants were randomly selected and treated according design: (1) removing sessile leaves, (2) removing short petiole leaves, (3) removing all leaves, (4) control (normal plants). At flowering ending stage, other plants were randomly selected and treated according: (1) removing all leaves, (2) shading silique from solar radiation, (3) control (normal plants). Aluminum foil paper was used in shading siliques, which was loosely wrapped around the silique and keeping vents on it to allow air circulation. The plants-treated were checked every 3–5 days to remove new leaves or shade new siliques according to the primary treatments. The experiments were harvested when siliques ripened. Each treatment was replicated in three plots (4.6 m × 10 m) and maintained a total 45 plants.

2.3. Measurement

Sample of stems, leaves, inflorescence (including flower buds, flowers and young siliques), siliques shell, and seeds of individual plant were gathered respectively at initial flowering stages, flowering ending stage, seeds filling stage (at 25th day after flowering ending) and seeds ripened stage. The samples were fixated at 105 °C for 15 min, then were dried to a constant weight at 60 °C and were weighed. These indexes were investigated in 20 plants replication.

Surface area of leaves or green silique was measured by a leaf area meter (Yaxin-1241, China) respectively at full flowering stage (7th day after initial flowering date), young siliques growth stage (7th day after flowering ending date) and seeds filling stage. When determining surface area of siliques, 50 green siliques were randomly picked from different position of a plant; the siliques shell were split and flattened along crack line, then surface area of the silique was tested by the leaf area meter. According to total siliques number, the total surface area of siliques on a plant was calculated. Above test was repeatedly measured in 20 plants.

Of the tested plants at full flowering stage or at 14th day after flowering ending, healthy leaves and siliques were selected to determine for photosynthetic indexes and photosynthetic pigments of chlorophyll a (*Chl* a), chlorophyll b (*Chl* b), chlorophyll a+b (*Chl* a+b) and carotenoid (*Car*) content (Gao, 2006). Ranking from top of the plant the first short stalk leaf on main stem, or the siliques on middle position of main inflorescence, was respectively selected to determine net photosynthetic rate (*P*n), stomatal conductance (*G*s) and transpiration rate (*T*r) by a portable photosynthesis system Li-6400 (USA) under natural temperature. The Measuring condition was set as an open-circuit gas channel system, 500 μmol s^{-1} air velocity, 400 μmol mol^{-1} CO_2 concentration and 1300 μmol m^{-2} s^{-1} photo-radiation intensity. The instanta-