Journal of Oilseed Brassica, 15 (1) : 33-42, January 2024

Growth pattern and yield of canola oilseed rape (*Brassica napus* L) as influenced by direct seeding and transplanting on different dates and irrigation

Jashanpreet Kaur[1]*, Virender Sardana[2], Vinay Sindhu[1] and Pushp Sharma[2]

[1]*Department of Agronomy,* [2]*Oilseeds Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana 141004 Punjab, India*
**Corresponding author: jashan16aug@gmail.com*
(*Received: 26 December 2023; Revised: 28 December 2023; Accepted:30 December 2023*)

Abstract

During the Rabi 2022-23 season, a field experiment took place at the Punjab Agricultural University, Ludhiana with the objective to investigate the impact of different dates of sowing and transplanting, as well as irrigation scheduling, on the growth and productivity of canola quality oilseed rape (*Brassica napus* L.) in sandy loam soil. Study comprised six combinations of three dates (10 October, 30 October and 20 November) and two methods of crop establishment (direct sowing and transplanting) as main plot and four irrigation schedules based on IW:CPE 0.8, IW:CPE 1.0, IW:CPE 1.2 and on crop growth stages as sub plot treatments. Treatments laid out in split plot design were replicated thrice. For transplanting, 30 days old seedlings were used. Irrigation based on crop growth stages was applied at 30 days after sowing, flowering and siliquae formation stages. Canola quality oilseed rape variety GSC 7 was sown/transplanted at spacing of 45 cm × 10-12 cm. Delay in sowing delayed the emergence. With delay in each sowing/transplanting from 10 October to 20 November, crop required significantly more number of days for initiation of flowering but less number of days for completion of flowering and physiological maturity. Delay in sowing/transplanting caused significant reduction in plant height, dry matter and PAR (photosynthetically active radiation) interception and number of primary branches plant^{-1}. Crop sown/transplanted on 10 October produced 16.8% higher seed yield than 30 October sown/transplanted crop (2719 kg ha^{-1}) which in turn significantly out yielded 20 November sown/transplanted crop by 60.0%. Transplanted crop took significantly less number of days for initiation and completion of flowering and physiological maturity than direct sown crop. Transplanted crop also attained significantly more plant height, accumulated significantly more dry matter and intercepted more PAR and produced 12.2% higher seed yield (2631 kg ha^{-1}) as compared to direct sown crop. Application of irrigations at IW:CPE 1.2 resulted in significantly higher plant height (except at maturity), DMA and PAR interception than other irrigation schedules. Irrigation application at IW:CPE 1.2 resulted in significantly higher seed yield (2559 kg ha^{-1}) as compared to the IW:CPE 0.8 (2402 kg ha^{-1}). The seed yield and harvest index of the crop that was transplanted on 30October was comparable to the crop that was directly sown on 10 October. However, the crop that was transplanted on 30October and 20November had a significantly higher seed yield compared to its direct sowing.

Keywords: *Direct sowing, growth, harvest index, irrigation, phenology, sowing/transplanting dates, yield*

Introduction

Oilseed rape (*Brassica napus* L.) is an important oilseed crop of family *Brassicaceae*. It has better tolerance to low temperature and frost than Indian mustard (*B. juncea*) and is resistant to white rust disease. Introduced in India in mid eighties, it has emerged as an important oil crop in irrigated areas of north India (Punjab, Himachal Pradesh and Jammu) and its cultivation can be extended to Kashmir, Haryana, Uttar Pradesh and Uttrakhand. Since the development of canola cultivars of rapeseed-mustard in which the oil contains very low amount of erucic acid (<2%) and defatted seed meal contains low amount of glucosinolates (less than 30 µmoles per gram), uses of oil for human consumption and defatted meal as a protein rich feed for livestock and poultry have increased mainly in the developed world. A number of canola cultivars of oilseed rape and Indian mustard have also been developed by the Punjab Agricultural University, Ludhiana, India (Anonymous, 2023).

Growth and productivity of a crop are significantly influenced by sowing time. Sowing at optimum time provides favourable environment for achieving its potential yield. However, in the intensive/multiple cropping systems, sowing of crops is often delayed which adversely impacts the yield. Low temperature at sowing up to vegetative stage of oilseed rape adversely affects germination, plant establishment and growth whereas, higher temperature at reproductive phase adversely affects development of yield contributing traits and reduces yield.

Early crop establishment through transplanting of seedlings can be a better alternative to minimize the yield losses. Oilseed rape can be successfully grown by transplanting (Anonymous, 2023). Under late sown conditions, transplanting resulted in higher seed yield and early maturity than direct seeding of oilseed rape (Buttar *et al*., 2006; Singh and Singh, 2013). However, effects of transplanting of oilseed rape on early dates have not been studied in India.

Crop yield is strongly influenced by water, availability of which is becoming a major constraint. Demand of water for agriculture and other sectors is increasing and to meet this demand, groundwater is being over exploited in the country. Maintenance of optimum moisture in the root zone is crucial for proper growth and development of plant and for mitigating moisture stress at critical crop growth stages (Singh *et al.,* 2021). Hence, it is crucial to possess a complete understanding of appropriate irrigation scheduling in order to maximize the potential yield and enhance water productivity of the crop. Consequently, the current study was undertaken to examine the impact of irrigation frequency and timing on the growth and productivity of canola oilseed rape, both directly seeded and transplanted on various dates.

Materials and Methods

The study was carried out at the research farm of Oilseeds Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana (30°54′ N and 75°48′ E, 247 m above mean sea level). Soil of the experimental field was sandy loam, neutral in pH, low in electrical conductivity, low in organic carbon and available nitrogen, rich in available phosphorus and available potassium. Field capacity and permanent wilting point of the one metre soil profile of experimental field were 25.4 cm and 10.2 cm, respectively.

Treatments comprised six combinations of three dates (10 October, 30 October and 20 November) and two methods of crop establishment (direct sowing and transplanting) as main plot and four irrigation schedules based on IW:CPE 0.8, IW:CPE 1.0, IW:CPE 1.2 and on crop growth stages as sub plot treatments. Treatments were laid out in split plot design and were replicated thrice. Canola oilseed rape variety GSC 7 was sown/transplanted at spacing of 45 cm × 10-12 cm. Gross plot size was 5.0 m × 3.6 m and net plot size was: 4.4 m × 2.7 m. One metre buffer was kept between plots.

For transplanting on 10 October, 30 October and 20 November, the nursery was sown one month prior to transplanting. For each date of transplanting, nursery bed of about 500 m^2 required for transplanting in one hectare was prepared by mixing 11.25 kg urea and 10 kg single super phosphate in soil at the last ploughing. Seed rate of one kg per ha was uniformly broadcast in the field and mixed well with the help of toothed rake (trangli) to produce enough number of seedlings for transplanting. Thereafter, a light irrigation was applied to the nursery bed after about 10 days of germination. Another light irrigation was applied to the nursery bed at 20 days after sowing. For transplanting, 30 days old seedlings (3-4 leaf stage) were used. Irrigation was applied immediately after transplanting of seedlings.

Basal application of recommended dose of phosphorus (30 kg ha^{-1}) was applied through SSP (single super phosphate) at the time of field preparation before last planking. Nitrogen (50 kg N ha^{-1}) through urea and potassium (15 kg K_2O ha^{-1}) through muriate of potash were also applied at sowing. Another dose of 50 kg N ha^{-1} through urea was applied after first irrigation.

Amount of irrigation water applied in each irrigation was 75 mm. Number of irrigations varied with dates of sowing/transplanting (10 October to 20 November) from 1 to 2 in case of IW:CPE 0.8, 2 to 3 in case of IW:CPE 1.0 and 2-4 in case of IW:CPE 1.2. In case of irrigations based on crop growth stages, three irrigations were applied at 30 days after sowing, flowering and siliquae formation stages. The total rainfall received during the crop season was 124.6 mm through 10 rainy days. The maximum mean weekly rainfall of 33 mm was received during 12th standard meteorological week. A maximum of 50.2 mm and minimum of 4.9 mm evaporation was recorded during 16th and 1st SMW, respectively.

Observations were recorded at 40, 80 and 120 days after sowing/transplanting and physiological maturity of the crop. Plant height, main shoot length, number of primary branches at each growth stage were recorded from 5 plants per plot. For dry matter, plant samples taken from 0.5 metre row length were dried first under shade and later in the oven at 65 ± 2°C till constant weight were obtained. For photosynthetically active radiation (PAR) interception, LI-COR-LINE Quantum sensor photometer was used to measure incoming and outgoing radiations at the top of the canopy and radiation transmitted to the ground surface. Observations were taken at random from two spots in each plot between 12:30 to 13:30 hrs. Chlorophyll content in leaves was measured with SPAD 502 Plus Chlorophyll Meter (Minolta Camera Co., Japan) from 10 randomly selected young fully opened leaves of different plants in each plot by taking precaution that midrib did not come under the sensor of the instrument. All data were statistically analyzed using computer software CPCS 1.0.

Results and Discussion

Growth pattern

Plant height and dry matter accumulation (DMA) increased with increase in age of the plant up to maturity and followed a sigmoid pattern of growth (Table 1). The maximum increase in plant height was observed between 40 and 80 days after sowing (DAS)/days after transplanting (DAT) (97.1 cm) followed by the period between 80 and 120 DAS/DAT (46.6 cm). The maximum net increase in DMA was recorded between 80 and 120 DAS/DAT (5444 kg ha^{-1}) followed by the growth period between 40 and 80 DAS/DAT (3495 kg ha^{-1}). The PAR interception increased up to 80 DAS/DAT and was lower at 120 DAS/DAT in comparison to that recorded at 80 DAS/DAT (Table 1). The SPAD chlorophyll value increased up to 80 DAS/DAT and decreased thereafter at 120 DAS/DAT and physiological maturity (Table 2).

Dates of sowing/transplanting

Crop sown on 20 November took significantly more number of days for initiation of emergence (6.6 days) and completion of emergence (9.8 days) than the crop sown on 30 October (4.8 and 8.0 days, respectively) and 10 October (4.2, 7.0 days, respectively). Consistent fall in maximum and minimum temperatures and reduction in sunshine hours under late sown conditions slowed down the process of emergence compared to early sowing dates. Mean temperature during first 10 days from each sowing date decreased from 24.7°C in case of 10 October sowing to 23.4°C in 30 October to 17.2°C in 20 November sowing date. Kumar and Rana (2013) opined mean air temperature of 24-28°C as the optimum for germination and seedling emergence of rapeseed-mustard. Similar effects of sowing dates on emergence were reported for delay in sowing from 15 October to 15 November in *B. napus* (Kaur *et al.,* 2018), from 10 October to 10 December in *B. carinata* (Singh and Dhingra, 2003), from 1 October to 30 October in *B. carinata* (Singh, 2016) and from 8 November to 18 December in *B. juncea* (Patel *et al.,* 2004) under similar agro-climatic conditions at different locations.

The crop sown/transplanted on 10 October attained significantly more plant height as compared to 30 October and 20 November sown/transplanted crop at all growth stages up physiological maturity (Table 1). Thus, crop sown/transplanted on 10 October attained 11.6, 2.3, 7.7 and 10.8 per cent more plant height at 40, 80, 120 DAS/DAT and maturity, respectively than 30 October sowing/transplanting, whereas it registered 46.3, 37.2, 32.9 and 37.5 per cent more plant height at 40, 80 and 120 DAS/DAT and maturity, respectively than 20 November sown/transplanted crop. Similarly crop sown/transplanted on 30 October attained 31.1, 37.0, 23.4 and 24.0 per cent more height than 20 November sown/transplanted crop at 40, 80 and 120 DAS/DAT and physiological maturity, respectively. Early sowing/transplanting (10 October) resulted in faster growth due to favourable environment for better availability and utilization of nutrients for increased meristematic cell division and cell elongation of plants. The crop sown/transplanted on later dates (30 October and 20 November) witnessed relatively lower temperature which led to delay in germination and slower subsequent growth and development of the plants.

Delay in sowing/transplanting from 10 October to 30 October to 20 November caused significant reduction in DMA at all growth stages except at 40 DAS/DAT when such reduction in 30 October over 10 October sowing/transplanting date was non-significant (Table 1). Crop sown/transplanted on 10 October produced 10.4, 11.7, 11.2 and 17.7 per cent more dry matter (DM) at 40, 80 and 120 DAS/DAT and physiological maturity, respectively than 30 October sown/transplanted crop and 17.8, 23.4, 52.9 and 62.3 per cent more dry matter at 40, 80 and 120 DAS/DAT and physiological maturity, respectively than 20 November sown/transplanted crop. Crop sown/transplanted on 30 October accumulated 6.7, 10.4, 37.4 and 37.9 per cent more DM at 40, 80 and 120 DAS/DAT and maturity, respectively than 20 November sown/transplanted crop. Early emergence, better establishment especially of the transplanted crop, increase in plant height and leaf area which provided more surface for photosynthesis during vegetative growth phase in the early sown/transplanted crop contributed to increased DMA than late sown crop.

Similar effect of different sowing dates on plant height and DMA of *B. napus* was reported by Kaur *et al.* (2018) and Bhagat *et al.* (2022). Kaur (2001) reported reduction in DMA of *B. carinata* with delay in sowing from 15 October to 15 December. Kumar *et al.* (2022) reported reduction in DMA of Indian mustard (*B. juncea*) with delay in sowing from second week of November to fourth week of November.

The PAR interception by crop sown/transplanted on 10 October was significantly higher than 30 October and 20 November sown/transplanted crop at all growth stages except at physiological maturity where such reduction in case of 20 November (56.0%) over 30 October (56.7%) sowing/transplanting date was inconspicuous (Table 1). Crop sown/transplanted on 10 October intercepted 8.1 and 9.3 per cent more PAR at 40 DAS/DAT, 12.5 and 36.7 per cent more PAR at 80 DAS/DAT, 8.7 and 12.2 per cent more PAR at 120 DAS/DAT, and 4.0 and 5.3 per cent more PAR at physiological maturity than 30 October and 20 November sown/transplanted crop, respectively. SPAD chlorophyll values differed significantly among sowing/transplanting dates at 40 and 120 DAS/DAT (Table 2). Successive delay in sowing/transplanting from 10 October to 20 November significantly decreased the accumulation of chlorophyll as indicated by lower SPAD values at both growth stages (40 and 120 DAS/DAT). This can be attributed to decreased growth and reduced leaf area of late sown crop. Earlier, Kaur *et al.* (2018) observed similar reduction in PAR interception and SPAD chlorophyll values with delay in sowing from 15 October to 30 October and 15 November in *B. napus*.

Crop sown/transplanted on 30 October took significantly more number of days (62.3 days) for initiation of flowering than 10 October (45.5 days) and 20 November (60.0 days) sown/transplanted crop. However, for completion of flowering, crop sown/transplanted on 10 October took significantly more number of days (99.5) in comparison to 30 October (97.4 days) and 20 November (95.5 days) sown/transplanted crop. Similarly there was significant reduction in number of days taken to reach physiological maturity for each delay in sowing/ transplanting (Table 2). Crop sown/transplanted on 10 October took 18.8 days more than 30 October sown/transplanted crop which took 8 days more than 20 November sown/transplanted crop to attain physiological maturity. Higher temperature, longer day length and more number of sunshine hours supplied the required heat units in less number of days to early sown/transplanted crop for initiation of flowering than later sowing dates which experienced gradual fall in temperatures (up to January) and reduced number of sunshine hours (particularly from mid December 2022 to mid January 2023). Mean temperature up to initiation of flowering date was 22.2°C, 16.0°C and 13.4°C in case of 10 October, 30 October and 20 November sowing/transplanting dates, respectively. Similarly, mean temperature during initiation to completion of flowering period was 13.2°C, 12.1°C and 15.8°C in case of 10 October, 30 October and 20 November sowing/transplanting dates, respectively. Singh *et al.* (2014) reported that sowing of Indian mustard on 29 November induced late flowering than 30 October and 14 November sowing due to low temperature during December and January. Kaur *et al.* (2018) also reported that 15 October sown *B. napus* took significantly less number of days for flowering initiation than 30 October and 15 November sown crop. During post flowering period particularly in case of delayed sowing/ transplanting, the crop was subjected to higher temperatures which hastened the rate of development and caused early maturity by shortening the reproductive phase in comparison to early sown/transplanted crop. Kumari *et al.* (2012) reported shorter growing period of late sown *B. juncea* due to high temperature during the reproductive phase. The results are in agreement with the findings of Kaur and Sardana (2018) for oilseed rape, Gupta *et al.* (2017) for Indian mustard and Akhter *et al.* (2014) for Brown Sarson (*B. rapa*) at different locations.

Crop sown/transplanted on 10 October produced 4.5 and 8.9 per cent longer main shoot (74.4 cm) than 30 October and 20 November sown/transplanted crop, respectively (Table 2). Number of primary branches per plant produced by the crop sown/transplanted on 20 November (6.4) was significantly lower than 30 October (7.3) and 10 October (7.7) sowing/transplanting dates. However, the effect of sowing/transplanting dates on production of secondary branches was non-significant. November sown/transplanted crop experienced lower temperature throughout its vegetative growth phase which slowed down the process of crop establishment and its growth in comparison to October sown/transplanted crop which also had longer crop duration. Similar effect of sowing dates on branching was reported by Kumar *et al.* (2022) and Kumar and Dhillon (2023) in *B. juncea*.

Crop sown/transplanted on 10 October produced 11.9 and 79.2 per cent higher (significantly) seed yield than 30 October and 20 November sown/transplanted crop, respectively (Table 2). Similarly, 30 October sown/transplanted crop out yielded 20 November sown/transplanted crop by margin of 60.0 per cent. This increase in seed yield in early sown/transplanted crop was the outcome of better growth (plant height, dry matter accumulation) led by enhanced PAR interception and chlorophyll content as compared to late sown/transplanted crop. The crop sown/transplanted on 10 October had longer reproductive phase i.e. period from initiation of flowering to physiological maturity (116.2 days) in comparison to 30 October (80.5 days) and 20 November (74.9 days) sown/transplanted crop. The increased length of the reproductive period in early sowing/transplanting provided more time for utilization of assimilates for development of yield contributing traits such as number of siliquae plant^{-1}, number of seeds siliqua^{-1} and 1000 seed weight which eventually contributed to seed yield in comparison to later sowing/transplanting dates. Similar reductions in seed yield of Indian mustard with successive delay in sowing from mid-October up to end November at different locations were reported by Singh *et al.* (2014) and Dinda *et al.* (2015) and for oilseed rape from 15 October to mid November were reported by Kaur *et al.* (2018).

Crop sown/transplanted on 10 October (24.4%) and 30 October (25.4%) registered statistically similar but significantly higher harvest index over 15 November (21.7%) sown/transplanted crop. Early sown/transplanted crop not only produced higher total biological yield (seed + stover) at maturity but also proportionately higher seed yield than later sown/transplanted crop. Seed yield in 20 November sown/transplanted crop was 44.2 and 37.5 per cent lower than 10 October and 30 October sown/transplanted crop whereas the stover yield in 10 and 30 October sown/transplanted crop registered reduction of 35.2 and 23.2 per cent, respectively.

Methods of crop establishment

Oilseed rape transplanted with 30 days old seedlings attained significantly more plant height than its direct seeding at all growth stages (Table 1). Such an increase in plant height in transplanted over direct seeded crop was 128.6, 48.1, 18.7 and 17.4 per cent at 40, 80 and 120 DAS/DAT and physiological maturity, respectively. Similarly, transplanted oilseed rape accumulated significantly more dry matter (22.2, 5.9, 19.8 and 13.1 per cent) than direct seeded crop (957, 4427, 9551 and 9994 kg ha^{-1}) at 40, 80 and 120 DAS/DAT and at physiological maturity, respectively (Table 1). Extended crop duration and favourable meteorological conditions for quick establishment of seedlings and growth contributed to increase in plant height and DMA of transplanted crop. Singh *et al.* (2006) reported significantly more plant height of African mustard (*B. carinata*) transplanted with 30 days old seedlings as compared to direct sown crop and the crop transplanted with 45 days and 60 days old seedlings at Ludhiana. Similar findings were reported by Aram *et al.* (2021) at Karaj, Iran for *B. napus* crop.

Transplanted oilseed rape intercepted significantly more PAR than direct sown crop at all growth stages (Table 1). However this difference narrowed down with advancing age of the crop (30.7, 10.1, 7.3 and 2.6 per cent at 40, 80 and 120 DAS/DAT and maturity, respectively). Transplanted crop also registered significantly higher values of SPAD (41.9, 47.7) than direct sown crop at 40 and 80 DAS/DAT (Table 2). However at 120 DAS/DAT, direct sown crop recorded significantly higher value of SPAD (43.1) than transplanted crop (41.9). Lower SPAD value is reflection of reduction in synthesis of chlorophyll pigments with advancing age of the crop. Lower SPAD value of transplanted than direct seeded crop at 120 DAS/DAT could be due to its more advanced stage of reproductive growth i.e. senescence stage.

Initiation of flowering in transplanted oilseed rape was much early (36.8 days from date of transplanting) in comparison to its direct seeding (75.1 days). Eventually transplanted crop took significantly lesser number of days for completion of flowering and physiological maturity than direct seeded crop (Table 2). Transplanted crop attained maturity (142.5 days) 8 days earlier in comparison to direct seeded crop. Application of irrigation immediately after transplanting of 30 days old seedlings and cooler environment provided favourable conditions for establishment of seedlings and completion of early vegetative phases at faster rate than direct seeded crop. Similar findings for *B. napus* were reported by Singh and Singh (2013) at Ludhiana and Aram *et al.* (2021) at Karaj, Iran.

The differences between transplanted and direct sown crop for main shoot length and number of primary and secondary branches per plant were inconspicuous (Table 2). Transplanting resulted in significantly higher (12.2%) seed yield (2631 kg ha^{-1}) than direct sown oilseed rape (Table 2). Increase in seed yield under transplanting accrued from better vegetative growth and early flowering and consequently enhanced reproductive growth period as compared to direct sown crop. These findings are in agreement with those reported from Assam by Singh *et al.* (2023) for Indian rape (*B. rapa*) and Indian mustard (*B. juncea*). Similar findings were reported by Singh *et al.* (2006) in *B. carinata* and Singh and Singh (2013) in *B. napus*. Rameeh (2019) reported significantly higher seed yield of transplanted *B. napus* as compared to direct sown crop. There was no significant effect of methods of crop establishment on harvest index of oilseed rape (Table 2).

Irrigation scheduling

Irrigation scheduling significantly influenced the plant height and DMA at all growth stages except plant height at physiological maturity (Table 1). Plant height with irrigation based on IW:CPE 1.2 and based on crop growth stages was significantly higher as compared to irrigation applied at IW:CPE 0.8 at 40, 80 and 120 DAS/DAT. Plant height with irrigation scheduled at IW:CPE 1.0 was also significantly higher than that recorded for irrigation scheduling at IW:CPE 0.8 at 40 and 80 DAS/DAT. Increase in plant height may be ascribed to assured availability of soil moisture to plants as a result of early and more number of irrigations in case of irrigation applied at IW:CPE 1.2, IW:CPE 1.0 and based on crop growth stages than at IW:CPE 0.8 throughout the crop growth. Similar beneficial effect of irrigation was reported by Panda *et al.* (2004) in *B. juncea* and Barick *et al.* (2020) in *B. compestris.*

Application of irrigation based on IW:CPE 1.2 resulted in significantly higher DMA by the crop at all growth stages than all other treatments except at 80 and 120 DAS/DAT over irrigation based on crop growth stages. Thus, irrigation based on IW:CPE 1.2 resulted in 10.3, 15.3 and 9.0 per cent more dry matter at 40 DAS/DAT (1153 kg ha^{-1}), 2.1, 4.6 and 1.3 per cent more dry matter at 80 DAS/DAT (4649 kg ha^{-1}), 7.1, 9.2 and 2.8 per cent more dry matter at 120 DAS/DAT (10469 kg ha^{-1}) and 5.0, 12.1 and 5.6 per cent more dry matter at physiological maturity (11253 kg ha^{-1}) than irrigation based on IW:CPE 1.0, IW:CPE 0.8 and crop growth stages, respectively. Irrigation based on crop growth stages and IW:CPE 1.0 also resulted in significantly more DMA than that of IW:CPE 0.8 at all growth stages. Higher dry matter could be attributed to more production and utilization of assimilates due to liberal availability of moisture. Similar findings were reported by Barick *et al.* (2020) for *B. compestris*.

Crop intercepted significantly more PAR with application of irrigation based on IW:CPE 1.2 and on crop growth stage basis than IW:CPE 0.8 and IW:CPE 1.0 at 40 DAS/DAT (Table 1). At later growth stages, irrigation applied at IW:CPE 1.2 resulted in interception of significantly more PAR than irrigation based on IW:CPE 0.8, IW:CPE 1.0 and on crop growth stages. Irrigation scheduling based on crop growth stages, IW:CPE 1.0 or IW:CPE 0.8 resulted in statistically similar PAR interception by the crop at all growth stages except at 80 DAS/DAT where PAR interception with irrigation based on crop growth stages (80.5%) was significantly higher than at IW:CPE 0.8 (77.4%). Irrigation application based on IW:CPE 1.2 resulted in significantly higher values of SPAD (41.0, 46.8) than irrigation based on IW:CPE 0.8 (40.2, 45.8), IW:CPE 1.0 (40.2, 46.0) and crop growth stages (39.9, 46.3) at 40 and 80 DAS/DAT (Table 2). With advancing age of the crop, the differences in SPAD value under different irrigation regimes became narrow due to reduced chlorophyll synthesis. Moisture stress caused by longer interval between irrigations under IW:CPE 0.8 or 1.0 or based on crop growth stages might have resulted in lower uptake of nutrients and consequently destruction of chloroplasts and reduction in synthesis of chlorophyll pigments in comparison to IW:CPE 1.2. Rad *et al.* (2015) reported similar findings in *B. napus*.

Irrigation scheduling did not influence the number of days required by oilseed rape for initiation and completion of flowering and physiological maturity of oilseed rape This might be due to adequate availability of moisture for the crop from soil profile under variable number of irrigations at different intervals for development of different phenophases.

Irrigation application based on IW:CPE 1.2 resulted in significantly longer main shoot (73.9 cm) as compared to irrigations based on IW:CPE 0.8 (70.8 cm) and based on crop growth stages (68.6). Early irrigation in case of IW:CPE 1.2 might have ensured higher meristematic activity, stomatal conductance, higher nutrient uptake and better allocation of biomass to different plant parts. Similar findings were reported by Kumar *et al.* (2022) and Piri and Sharma (2011) in *B. juncea*. Numbers of primary and secondary branches per plant were not influenced by time of irrigation.

Among different schedules of irrigation, IW:CPE 1.2 resulted in significantly higher seed yield (2559 kg ha^{-1}) as compared to the IW:CPE 0.8 (2402 kg ha^{-1}) but was at par with IW:CPE 1.0 (2505 kg ha^{-1}) and irrigation based on crop growth stages (2484 kg ha^{-1}). As a result of longer interval between successive irrigations based on IW:CPE 0.8 in comparison to IW:CPE 1.0 and 1.2, and irrigation based on crop growth stages, the crop might have suffered from moisture stress which adversely affected the nutrient uptake and reduced the reproductive growth period and development of yield contributing traits. More translocation of assimilates to reproductive structures owing to sufficient soil moisture contributed to higher seed yield under different irrigation schedules as compared to IW:CPE 0.8. Shivran *et al.* (2018) also reported higher seed yield of Indian mustard with three irrigations applied at 35, 65 (flowering) and 95 (siliqua development stage) DAS as compared to no post sowing irrigation, one irrigation at 30-35 DAS, one irrigation at flowering, two irrigations at 30-35 DAS and flowering, two irrigations at 30-35 DAS and siliqua development stages. Sharma *et al.* (2021) reported higher seed yield of *B. napus* with drip irrigation at IW:CPE 1.0 as compared to IW:CPE 0.8 and IW:CPE 0.6. Different irrigation scheduling treatments had non-significant effect on harvest index of oilseed rape (Table 2).

Interactive effect of dates and methods of crop establishment

Direct sown and transplanted crop on 10 October produced similar seed yield (3044 kg ha^{-1}). However, in later dates (30 October and 20 November), transplanted crop produced significantly higher seed yield than its direct seeding (Table 3). Under both methods of crop establishment (direct sowing and transplanting), seed yield in case of 10 and 30 October was significantly higher than 20 November sown/transplanted crop (Table 3). Crop sown or transplanted on 10 October also produced significantly higher seed yield than direct sown crop on 30 October. Successive delay of 20 days in direct sowing from 10 October to 20 November caused significant reduction in seed yield. In case of direct sowing, delay in sowing from 10 October to 30 October significantly reduced the seed yield by 26.3 per cent whereas, further delay in sowing from 30 October to 20 November caused seed yield reduction of 52.7 per cent. Under transplanting method, delay in sowing from 10 October to 30 October caused reduction of only 0.5 per cent in seed yield. However, further delay from 30 October to 20 November reduced the seed yield by 66.4 per cent. However, seed yield of crop transplanted on 30 October (3029 kg ha^{-1}) and 20 November (1820 kg ha^{-1}) was 25.7 and 15.3 per cent higher than its direct seeding on respective dates (2409 and 1578 kg ha^{-1}). The highest seed yield obtained with transplanting on 10 October might be due to longer growing period and favourable weather conditions which helped in better growth and development of the oilseed rape. Similar findings were reported by Singh *et al*. (2019) for *B. juncea*. Rameeh (2019) reported significantly higher seed yield of transplanted *B. napus* as compared to direct seeded crop. Crop transplanted on 10 October registered significantly higher harvest index (31.1%) than crop transplanted on 30 October and 20 November and also over all dates of

Table 1: Effect of dates and methods of crop establishment and irrigation scheduling on emergence, plant height and dry matter accumulation and interception of photosynthetically active radiation by oilseed rape at different growth stages

Treatments	Days taken for emergence		Plant height (cm)				Dry matter accumulation (kg ha^{-1})				Interception of photosynthetically active radiation (%)			
			Days after sowing/transplanting				Days after sowing/transplanting				Days after sowing/transplanting			
	Initiation	Completion	40	80	120	Maturity	40	80	120	Maturity	40	80	120	Maturity
Dates of sowing/ transplanting														
10 October	4.2	7.0	33.5	142.0	192.0	201.8	1159	5055	11753	12961	67.5	91.9	83.8	59.0
30 October	4.8	8.0	30.0	136.3	178.2	182.0	1050	4524	10567	11010	63.7	81.3	77.0	56.7
20 November	6.6	9.8	22.9	99.5	144.4	146.8	983	4096	7688	7984	52.9	67.2	74.7	56.0
SEm±	0.2	0.3	0.6	0.8	1.3	1.1	35	45	326	280	1.7	0.7	0.7	0.3
CD (p=0.05)	0.6	0.8	1.8	2.5	4.0	3.5	110	141	1027	883	4.8	1.5	2.2	0.8
Methods of crop establishment														
Direct sowing	-	-	17.5	100.3	156.8	162.7	957	4427	9551	9994	46.0	74.9	74.8	56.0
Transplanting	-	-	40.0	151.6	186.2	191.0	1170	4690	10455	11309	76.7	85.0	82.2	58.6
SEm±	-	-	0.5	0.6	1.0	0.9	28	36	266	229	1.4	0.5	0.6	0.2
CD (p=0.05)	-	-	1.5	2.0	3.3	2.8	90	115	839	721	3.9	1.2	1.8	0.7
Irrigation scheduling														
IW:CPE 0.8	-	-	27.2	99.5	167.7	173.8	1000	4445	9582	10038	52.3	77.4	76.9	57.0
IW:CPE 1.0	-	-	28.8	130.9	169.9	178.4	1045	4553	9775	10714	60.9	79.0	78.2	56.9
IW:CPE 1.2	-	-	30.4	137.1	175.5	179.5	1153	4649	10469	11253	65.9	83.0	80.7	58.3
Based on crop	-	-	28.7	136.5	172.9	175.7	1058	4588	10185	10602	64.4	80.5	78.1	57.0
SEm±	-	-	0.4	0.9	0.9	1.5	16	30	126	132	1.1	0.6	0.6	0.2
CD (p=0.05)	-	-	1.1	2.7	2.6	NS	45	88	363	377	3.0	1.9	1.8	0.7

Table 2: Effect of dates and methods of crop establishment and irrigation scheduling on SPAD chlorophyll value at different growth stages, days to flowering, maturity, main shoot length, branching, seed yield and harvest index of oilseed rape

Treatments	SPAD chlorophyll				Days taken for			Main shoot length (cm)	Primary branches per plant	Secondary branches per plant	Seed yield (kg ha^{-1})	Harvest index (%)
	40 Days	80 Days	120 Days	Maturity	Initiation of flowering	Completion of flowering	Maturity					
Dates of sowing/ transplanting												
10 October	42.3	46.3	44.2	35.9	45.5	99.5	161.7	74.4	7.7	8.2	3044	24.4
30 October	41.2	46.4	42.0	36.1	62.3	95.5	142.9	71.2	7.3	8.2	2719	25.4
20 November	37.4	46.0	41.3	35.4	60.0	97.4	134.9	68.3	6.4	7.6	1699	21.7
SEm±	0.3	0.2	0.3	0.2	0.4	0.6	0.2	1.2	0.2	0.3	48	0.3
CD (p=0.05)	0.9	NS	0.9	NS	1.2	1.9	0.7	3.4	0.7	NS	152	1.1
Methods of crop establishment												
Direct sowing	38.8	44.7	43.1	35.8	75.1	106.4	150.5	70.8	6.9	7.7	2344	23.8
Transplanting	41.9	47.7	41.9	35.8	36.8	88.5	142.5	71.7	7.4	8.3	2631	23.8
SEm±	0.2	0.1	0.2	0.2	0.3	0.5	0.2	0.9	0.2	0.2	39	0.3
CD (p=0.05)	0.8	0.4	0.7	NS	1.0	1.6	0.6	NS	NS	NS	124	NS
Irrigation scheduling												
IW:CPE 0.8	40.2	45.8	42.6	35.7	55.8	97.3	146.1	70.8	7.0	7.5	2402	23.6
IW:CPE 1.0	40.2	46.0	42.4	35.8	56.2	97.2	146.7	71.9	7.1	7.9	2505	24.5
IW:CPE 1.2	41.0	46.8	42.4	36.1	55.5	97.5	146.8	73.9	7.4	8.6	2559	24.1
Based on crop growth stages	39.9	46.3	42.6	35.5	56.2	97.8	146.4	68.6	7.1	7.9	2484	23.2
SEm±	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.8	0.2	0.3	53	0.4
CD (p=0.05)	0.5	0.6	NS	NS	NS	NS	NS	2.4	NS	NS	140	NS

direct sowing (Table 3). Similarly, crop transplanted on 20 November registered significantly higher harvest index (22.6%) than its direct seeding (20.7%). Crop transplanted on 30 October registered statistically similar harvest index with direct sown crop on 10 October and 30 October. Crop sown/transplanted on 30 October registered significantly higher harvest index than direct sown/transplanted crop of 20 November.

Table 3: Interactive effect of dates and methods of crop establishment on seed yield and harvest index of oilseed rape

Date of sowing/ transplanting	Method of crop establishment			
	Direct sowing	Transplanting	Direct sowing	Transplanting
	Seed yield (kg ha^{-1})		Harvest index (%)	
10 October	3044	3044	25.5	31.1
30 October	2409	3029	25.2	25.6
20 November	1578	1820	20.7	22.6
SEm±	68		0.5	
CD (p=0.05)	215		1.5	

Conclusion

Delay in sowing/transplanting delayed emergence and flowering but reduced crop duration, caused significant reduction in plant height, biomass, branching and yield. Transplanted crop took significantly less number of days for flowering and physiological maturity, attained more height, accumulated more dry matter and intercepted more PAR and produced higher seed yield as compared to direct sown crop. Application of irrigations at IW:CPE 1.2 was found optimum for better growth and yield. Seed yield of crop transplanted on 30 October was at par with direct sown crop on 10 October. Crop transplanted on 30 October and 20 November produced significantly higher seed yield than its direct sowing. Therefore, it can be concluded that higher yield of oilseed rape can be obtained by transplanting than direct sowing particularly under delayed sowing conditions.

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