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REVIEW ARTICLE

Manipulation of source -sink ratio by destruction of capitulum core florets to increase the seed filling, yield and quality in sunflower

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Abstract

The yield of sunflowers is impacted by inadequate source-sink connections. There are no vascular bundles in the center of the capitulum, resulting in low seed setting and filling. It was hypothesized that manipulation of resource availability to peripheral and intermediary seeds by eliminating the predominantly ill-filled seeds of the capitulum core would have an augmenter effect on the filling of seeds in the rest of the two regions. A field experiment was conducted to achieve capitulum core destruction by operating a newly designed hand-held battery-operated 'capitulum core destructor', capable of removing the core area to a diameter of 0.8 and 1.5 cm. Field experiments were conducted to standardize the optimum stage for capitulum core destruction (R5.0- 0% flowering of the capitulum total area (disc florets), R5.1- 10% flowering, R5.4- 40% flowering, R5.8- 80% flowering) and optimum area of core destruction (0.8 and 1.5 cm of inner diameter). The results revealed that the core destructed treatments outperformed the control (T_1) in terms of seed yield and seed quality attributes. Amongst the treatments, T_5 (1.5 cm core destruction at R5.8 stage) showed a 21% increase in seed yield over the control and registered the highest total number of seeds, total seed weight (48.63 g) and 100-seed weight (g). Additionally, the T_5 treatment improved seed recovery percentage (80.23% compared to 70.45% in the control) and reduced rejected seed percentage (19.76% compared to 29.54% in the control). Concomitantly, the resultant seeds of T_5 (1.5 cm core destruction at R5.8 stage) also possessed the highest germination potential, speed of germination, seedling growth and vigour index. This study demonstrates a scalable approach for sunflower cultivation globally, offering a practical solution to enhance yield and quality. Therefore, it was concluded that capitulum core destruction optimized resource allocation among the periphery and middle whorls of the capitulum, thereby resulting in a significant augmentation of seed yield and quality potential in sunflower crops.

Keywords

capitulum; core destruction: floret; sunflower; yield

Introduction

Sunflower (*Helianthus annuus* L.) is one of the important oilseed crops in India. In India, sunflower is mainly used as edible oil and is the fourth most important oilseed crop after groundnut (*Arachis hypogea* L.), mustard

(*Brassica napus* L.) and soybean (*Glycine max* L.). The Indian states of Karnataka, Maharashtra, Andhra Pradesh and Tamil Nadu are the main producers of sunflower. Sunflower offers great potential as it has wide adaptability, short duration (90-100days) of maturity, drought tolerance and photo-and thermo-insensitivity, which enables it to fit in different cropping systems (1). Sunflower seeds are considered a 'functional food' owing to their benefits beyond basic nutrition. More polyunsaturated fatty acids (60%), such as oleic acid (16.0%) and linoleic acid (72.5%), which regulate blood cholesterol, are found in sunflower oil (2). Therefore, there is a great demand for sunflower oil, which offers great scope for improving the area of sunflower cultivation.

Sunflower production is a vital agricultural activity that faces numerous global challenges, including climate change, pests, diseases and market fluctuations. These challenges vary across different agro-climatic zones, necessitating adaptive strategies for maintaining high yields and quality. One critical approach is optimizing source-sink relationships, which involves balancing the production of photosynthates (sources) and their utilization in growth and development (sinks). By enhancing source-sink dynamics, sunflower plants can achieve better resilience to environmental stresses, higher yields and improved nutritional quality of seeds (3). This article explores the global challenges in sunflower production and emphasizes the significance of optimizing source-sink relationships to ensure sustainable and productive agriculture in diverse agro-climatic zones.

However, one of the major constraints in the cultivation of sunflower is the low productivity compared with the other oilseed crops. One of the major reasons for low productivity is reported to be low seed setting as well as seed filling (4). It is believed that inadequate vascularization, or the lack of vascular bundles in the capitulum's central region, is the primary physiological cause of poor seed filling. As a result, solutes are indirectly transported horizontally from peripherally positioned vascular bundles to the intermediate and centrally located seeds. Due to this, seeds situated in the periphery of the capitulum receive a higher assimilate supply compared to seeds in the intermediary and central region of the capitulum (5). Ultimately, the percentage of empty achenes in the peripheral area of the capitulum is lesser (3-6%), while in the central zone, the emptiness increased exponentially, even up to 51%. Earlier studies indicate that a threshold level of assimilate(sources) supply is required for seed set (sink) and therefore, increasing the total assimilate supply will allow a greater number of seeds to set and continue to develop (6). The generation of assimilates by leaves and the subsequent consumption of these assimilates by developing seeds affect the yield of any crop (7). Therefore, apart from assimilating production, remobilization of assimilates from the source to the sink is necessary for improving the yield potential of any crop.

The novelty of this study lies in the development and implementation of the "capitulum core destructor," a unique, hand-held, battery-operated tool designed specifically to address the persistent issue of source-sink imbalance in sunflower cultivation. Unlike traditional approaches that rely on agronomic or chemical interventions to improve seed set and yield, this study introduces a precise mechanical method for manipulating resource allocation within the capitulum. By selectively removing the core region, which is physiologically less efficient due to the absence of vascular bundles, the device ensures that assimilates are redirected to the more productive peripheral and middle regions of the capitulum. This innovation builds upon prior research that identified the problem of inadequate vascularization in the capitulum core but lacked a practical, field-deployable solution to address it. For instance, studies like those by (8, 9) highlighted the potential of source-sink manipulation in enhancing yield; however, their methods primarily involved manual trimming or growth regulator applications, which were time-intensive and inconsistent in achieving the desired outcomes. The "capitulum core destructor" advances these efforts by providing a standardized, efficient and scalable tool that can be used across varying field conditions.

The capitulum three whorls of the core, center and periphery are compete with one another for assimilation in sunflowers, leading to a defective core region. Compared to the later-formed core seeds, the peripheral and intermediate seeds have greater sink strength because they are the early-formed seeds and have more time to accumulate assimilate. Due to source limitation, there is a greater percentage of empty achenes (up to 60%), particularly in the capitulum's core. Remobilization of carbohydrates from other parts of the plant can also contribute to seed growth during photosynthesis. The mechanical destruction of capitulum at the central region at the 60th DAS, resulted in a 6% increase in the yield over capitulum maintained without destruction and source sink manipulation in sesame helped in achieving higher yield (8, 9). The concentration of cytokinin was important in seed setting of soybean. The concept of trimming the competition for scarcely available resources, by removing a part of reproductive organ has been effective in enhancing the reproductive potential and yield of the crop (10, 11).

Against this background, a study was formulated to elucidate the effect of capitulum core destruction in preventing assimilate partitioning to the central region and thereby improving the seed productivity in sunflower var. CO4. The objectives of the study were to develop a handheld battery operated 'fan-type' capitulum core destructor and standardize the optimum area of destruction as well as stage of destruction to obtain the highest seed filling and seed yield.

Materials and Methods

Sunflower seeds of var. CO4, purchased from the Department of Oilseeds, Tamil Nadu Agricultural University, Coimbatore were used in the study. This variety was selected due to its agronomic importance, adaptability to local conditions and its well-defined capitulum structure, making it ideal for evaluating the impact of core destruction treatments. Laboratory tests were carried out at the Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore, while field trials were carried out at the Eastern block, Department of Farm Management, Tamil Nadu Agricultural University, Coimbatore. The trials were carried out over a during kharif season, in a plot size of 5 × 4 m^2, with sunflower crops cultivated under recommended agronomic practices, including a spacing of 60 × 30 cm in 10 cents area. The experimental area had well-drained loamy soil and trials were conducted under optimal irrigation and fertilization conditions to ensure uniform crop growth.

Experiment 1:Development of handheld battery operated 'capitulum core destructor' for sunflower

The battery-operated Bosch Screwdriver was modified by replacing the screw driving attachment with a circular disc (disc of two sizes *viz.,*0.8 cm and 1.5 cm) containing three radiating blades (Fig. 1 and 2). The disc rotates both in the clockwise and anti-clockwise direction. In the center of the disc, a pointed projection was provided to poke into the capitulum and to gain anchorage during the disc rotation process. The equipment contains a Li-ion battery that does not face self-discharge and is always ready for use with stability and weighs 300 g. The battery features a voltage of 3.6V that helps to achieve a torque of 3-4 N, rotates the disc with blades swiftly and mechanically destructs the capitulum core region. The maximum speed is 180 rpm. The battery-operated capitulum core destructor is capable of destructing the core of a capitulum within 5-10 seconds. The core destruction of 250-300 capitulum can be achieved in an hr.

Experiment 2: Standardization of optimum stage of capitulum development and area of core destruction for enhancing the seed filling of sunflower

A field experiment was conducted, adopting a Randomized Block Design (RBD) with four replications. The experimental plot was prepared at the size of 5x4 m^2 and the seeds were sown in 60x30 cm^2 spacing. The crop was cultivated following the recommended agronomic practices. Four stages of capitulum development *viz*., 0% flowering of total area (disc floret), 10% flowering of total area (disc florets), 40% flowering of total area (disc florets), 80% flowering of total area (disc florets) and these stages were designated as R5.0, R5.1, R5.4 and R5.8 respectively (10) (Fig. 3). These stages were selected because they represent key phases in capitulum development where assimilate allocation to seeds is critical. In this "R" reffered as reproductive stage At R5.0 and R5.1, resource allocation begins as early peripheral florets initiate seed development, while at R5.4 and R5.8, competition for assimilates among the peripheral, middle and core regions intensifies, making these stages ideal for investigating source-sink manipulations.

Likewise, the area of core destruction (diameter 0.8 cm and 1.5 cm) of the sunflower capitulum was executed to impose the treatments given below by operation of the newly designed hand-held battery-operated capitulum core destructor, as described in Experiment 1. The experiment had five treatments viz., T_1- Control (No core destruction), T_2 -0.8 cm core destruction at R5.0 stage, T_3 -0.8 cm core destruction at R5.1 stage, T_4 -1.5 cm core destruction at R5.4 stage and T_5 -1.5 cm core destruction at R5.8 stage. After imposing the treatments, the following capitulum traits (i) capitulum diameter (cm), (ii) fresh weight (g) and (iii) dry weight (g) were observed. Also, various seed yield and seed quality attributes were recorded.

Seed yield attributes

Ten capitulum was earmarked as periphery, middle and core region and the observations *viz*., (i) number of filled seeds, (ii) number of ill-filled seeds, (iii) weight of filled seeds and (iv) weight of ill-filled seeds were recorded. Further, the following observations (i) total number of filled seeds per capitulum, (ii) total number of ill-filled seeds per capitulum, (iii) total number of seeds per capitulum, (iv) 100 seed weight, (v) total weight of filled seeds per capitulum, (vi) total weight of ill filled seeds per capitulum, (vii) total weight of seeds per capitulum, (viii) individual seed size, (ix) seed set (%), (x) seed recovery percentage and (xi) rejected seed percentage were recorded in 10 selected capitulum.

Seed quality attributes

The filled seeds obtained from the periphery, middle and core regions from each treatment were subjected to a germination test with four replicates of 100 seeds in paper medium (12). The test conditions were 25±2° C and 95±5% RH, illuminated with fluorescent light. The seeds were

Fig. 1. Hand-held battery-operated Bosch Screwdriver.

Fig. 2. Newly designed disc with three radiating blades and pointed projection.

S. No	Stages	Description	Image
1.	R5.0	Beginning of flowering (0% flowering of total area (disc florets) in the capitulum	
2.	R5.1	10% flowering of total area (disc florets) in the capitulum	
3.	R5.4	40% flowering of total area (disc florets) in the capitulum	
4.	R5.8	80% flowering of total area (disc florets) in the capitulum	

Fig. 3. Periphery, middle and core regions of sunflower.

monitored daily up to 14 d for radicle protrusion. After the germination period of 10 d, the seedlings were evaluated as normal and abnormal seedlings and dead seeds. The number of normal seedlings was expressed as germination percentage.

Statistical analysis

To unify the variance of the data, the data (in %) were converted to arcsine values prior to statistical analysis (13). Similarly, the complete set was log transformed (log base 10) if the outcome data included specific treatments that had no values. Following that, the data were examined using the F test for significance, as explained in (14) and the LSD test was used to compare treatment averages at the 0.05 level of probability.

Results and Discussion

Experiment 1:Development of handheld battery operated ‘capitulum core destructor’ for sunflower

A battery-operated screwdriver (Bosch- GO 2.0) was purchased and the head portion of the screwdriver was replaced with a fantype radiating steel blade (Fig. 1 and 2). When the ‘ON’ button was pressed, the steelhead with radiating steel blades rotated swiftly with an rpm of 180 rpm. When the swiftly rotating head was pressed on the capitulum of sunflower, it destructed the flowers in that particular area (Fig. 4). The circular steel head with radiating blades were made in two variants viz., diameter of 0.8 cm and 1.5 cm, so as to achieve two different sizes of capitulum core destruction. The newly fabricated instrument will be hereafter indicated as ‘capitulum core destructor’.

Fig. 4. Capitulum core destruction at R5.8 stage (80% flowering stage).

Experiment 2: Standardization of optimum stage of capitulum development and area of core destruction for enhance the seed filling of sunflower capitulum

At first, the core region of the tagged capitulum (70 nos.) was destructed with the newly developed ‘capitulum core destructor’ @ 0.8 cm diameter when the crop was in R 5.0 (0% flowering), R5.1 (10% flowering). Later when the capitulum reached the size of R5.4 (40% flowering) and R5.8 (80 % flowering), the capitulum core was destructed to a level of 1.5 cm diameter. After the treatment, the capitulum was marked as peripheral, middle and core region in order to make the various observations on the seed set (Fig. 5). When the capitulum was destructed @ 0.8 cm diameter, three regions were earmarked *viz.,* peripheral, middle and core region since central region was only partially destructed, however, when the destruction was @ 1.5 cm diameter, only peripheral and middle regions were observed since the entire core region was destructed. For implementing the management practices we need additional 8 lobourers/ha.

Fig. 5. Periphery, middle and core regions of sunflower .

Capitulum characteristics

In the stages of capitulum development and area of capitulum core destruction, no significant difference was observed in the capitulum diameter. However, capitulum fresh and dry weight recorded was found to be the highest in 1.5 cm dia. core destruction (R 5.8 stage) treatment (T_5) with 552.6g and117.5g, respectively. All the same, the minimum values were registered in control (T_1) (474.1 g and 102.4 g, respectively) (Table 1).

Seed yield attributes

The highest seed set percentage of 82.9% was observed in T_5, which was significantly higher than the control (67.2%, LSD at 5%= 2.35). The number of filled seeds capitulum^{-1} was found to be the highest in the peripheral (432.5) and the middle region (419.3)in T_5 (1.5 cm core destruction at R5.8 stage), recording 6% and 21% increase over the control (T_1), respectively. It was observed that '1.5cm capitulum core destruction' T_4 (R5.4 stage) and T_5 (R5.8 stage) helped to achieve a comparatively higher number of filled seeds in the middle region of the capitulum (Fig. 6). However, the total number of filled seeds capitulum^{-1} recorded was found to be the highest in 0.8cm core destruction at R5.1stage (T_3) (883.7), owing to its presence of filled seeds in periphery, middle and core region (Fig.10). With respect to the number of ill-filled seeds capitulum^{-1}, T_5 recorded a minimum number of 83.1 and 92.2 in the peripheral and middle region, respectively, while the maximum value was recorded in T_1 (102.5 and 110.7, respectively) (Fig. 6). The total number of seeds capitulum^{-1} was maximum in T_1 (1257.8) but this was achieved due to the presence of the highest number of ill-filled seeds (412.4) (Fig. 7). Similar findings were reported by (8, 9), where source-sink manipulation in sunflower resulted in a 6% yield increase, emphasizing the critical role of assimilate redirection. Additionally, observed enhanced yield in sesame following source-sink adjustments, attributing the improvements to reduced competition among reproductive structures. The assimilate translocation pattern in the earlier-formed and later formed pods in soybean accounted for 70 and 30%, respectively, indicating that earlier formed pods received more assimilates compared to the later-formed pods (15). The % of full seeds was greater in the outer whorl and decreased toward the core whorl, further studied about the physio chemical properties of seeds.In the central region, there was a 10-fold decrease in filled to unfilled seed ratio (16). Corroborating these results in the present study, capitulum core destruction *i.e.,* removal of dysfunctional central whorl, had enabled transfer of greater part of photosynthates to the peripheral and middle whorls (early formed) by reducing the partitioning to central core region. Eventually, the total number of filled seeds per capitulum increased, resulting in improved seed yield. The findings are in conformity with (17) in groundnut, where assimilate sink strength of the earlier-formed pods has been greater than the later-formed ones, resulting in a high rate of podset, in turn, higher yields and same was observed in pigeonpea (7) and mung bean (18). Unlike these studies, the present research highlights the novel use of a mechanical core

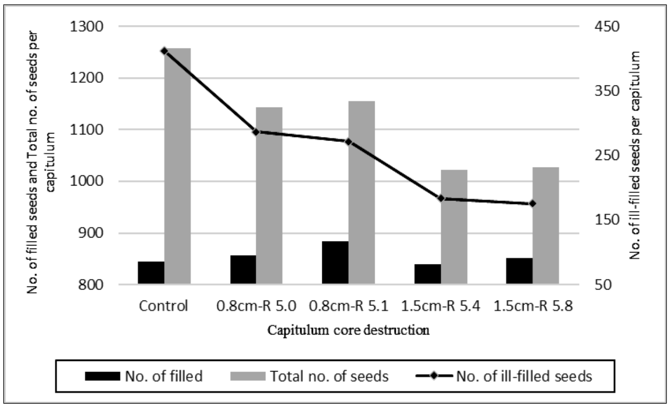

Fig. 6. Effect of capitulum core destruction treatments on the total number of seeds, filled seeds and ill-filled seeds.

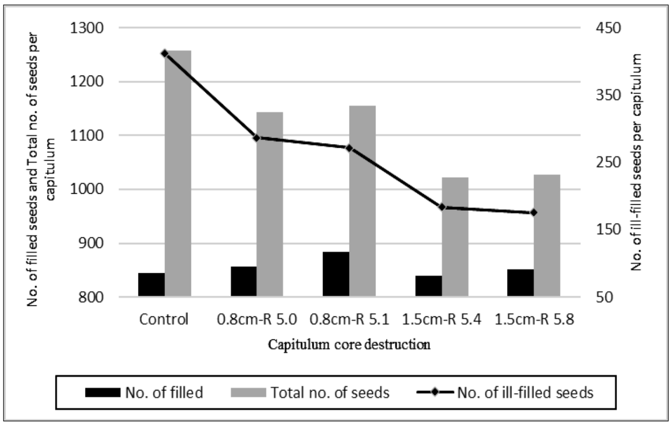

Fig. 7. Effect of capitulum core destruction treatments on total number of seeds .

Table 1. Effect of stage and area of capitulum core destruction on capitulum diameter (cm), capitulum weight (g) in sunflower var. CO4

Treatments (T)		Capitulumdiamete (cm)	Capitulum freshweight (g)	Capitulumdry weigh (g)
T_1	- Control (without core destruction)	16.34	474.1	102.4
T_2	- 0.8cmcore destruction at R5.0 stage	16.62	490.3	103.8
T_3	- 0.8cmcore destructionatR5.1stage	16.80	512.8	109.5
T_4	- 1.5cmcore destructionatR5.4stage	17.42	539.7	114.8
	- 1.5cmcoredestructionat R5.8stage	17.66	552.6	117.5
T_5	Mean	16.96	513.9	109.6
	SED	1.83	5.25	1.74
	CD (P = 0.05)	NS	11.44	3.79

destructor for precise assimilate redistribution, resulting in a remarkable 21% increase in seed yield in the T5 treatment, a unique outcome not previously reported in sunflower studies.

The highest weight of filled seeds was recorded in the periphery (26.13 g) and middle (22.59 g) region in the T_5 (1.5 cm core destruction at R5.8 stage) by recording 29 and 32 percent increase over T_1 (control) (Fig. 8). The highest total weight of filled seeds per capitulum was also recorded in T_5 (47.72 g, LSD at 5%= 1.74) despite the complete removal of whorls in central region. with respect to the weight of ill-filled seeds also the highest value was recorded in T_5 (1.5 cm core destruction at R5.8 stage), by registering 0.442 g and 0.463 g in the peripheral and middle region, respectively, while the lowest was recorded in T_1 *viz.,* 0.421g and 0.440g, respectively. In the core region, T_1 recorded the highest of 0.905 g, which in turn accounted for the highest total weight of ill-filled seeds in T_1 (Fig. 9). In conclusion, the highest total weight of seeds per capitulum was achieved inT_5 (48.63g) which was 15% increase over T_1 (Fig. 9). Likewise, the same trend was observed in 100 seed weight of filled and ill-filled seeds in the peripheral and middle region (Fig. 10).

The variations in blossom retention had a major impact on the quantity and mass of mature pods produced by each plant as well as the quantity of seeds in groundnut. In the present study, T_5 (1.5 cm core destruction at R5.8 stage) recorded the highest total weight of seeds per capitulum, proving that the removal of core region enabled the supply of assimilates to the peripheral and middle region resulting in increased crop yield (19). Similar findings were reported in wheat, ½ spikelet removal with no defoliation and ½ spikelet with ½ leaves removal had improved the resultant seed weight by 10% respectively over the control (20).

Seed recovery percentage was also found to be highest inT_5 (1.5 cm core destruction at R5.8 stage) (80.23%), while the T_1 recorded the lowest of 70.45 % (Fig. 11). The rejected seeds percentage was also found to be the highest in T_1 (29.54%) while the lowest was in T_5 (19.76%) (Fig. 11). Rejected seed % was maximum in control due to the presence of higher number of ill filled seeds which resulted due to higher competition of assimilates compared to T_5. Likewise, the seed sizes of T_5 were larger compared to T_1.

The increase in the seed yield attributes in T_5 (1.5 cm core destruction at R5.8 stage) had resulted in concomitant increase in seed yield plot^{-1}, computed seed yield ha^{-1} which recorded the highest values of 16 kg and 1080 kg, respectively, while the lowest was recorded in T_1 (control) *viz.,*1.79 kg and 895 kg respectively. T_5 recorded 21% increase over T_1 (Table 2).

Yield is an indicator of the physiological processes occurring in plants over time and is related to the dry matter production. In general, crop yield depends not only on the accumulation of photo assimilates during crop growth and development but also on the partitioning of assimilates to the desired storage organs (21). Crop reserve partitioning, growth and development are in turn controlled by the balance between sources and sinks

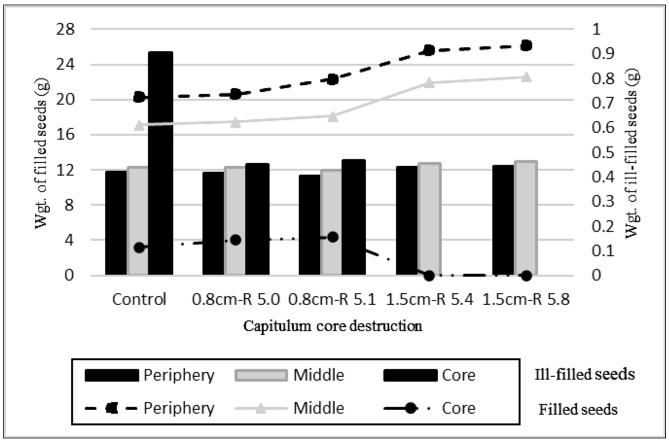

Fig. 8. Effect of capitulum core destruction treatments on the total weight of seeds, weight of filled seeds and ill-filled seeds.

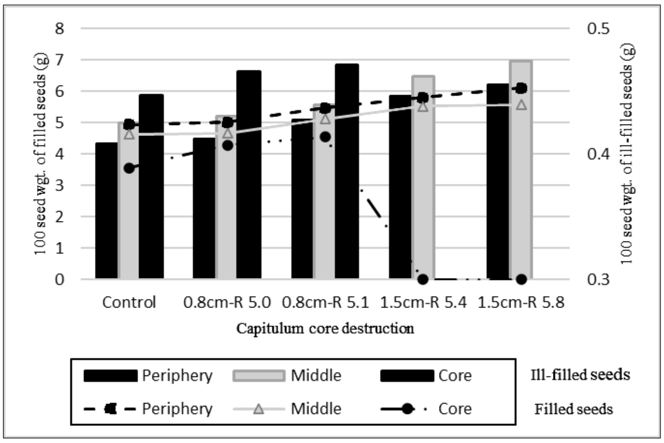

Fig. 10. Effect of capitulum core destruction treatments on the 100 seed weight of the filled and ill filled seeds.

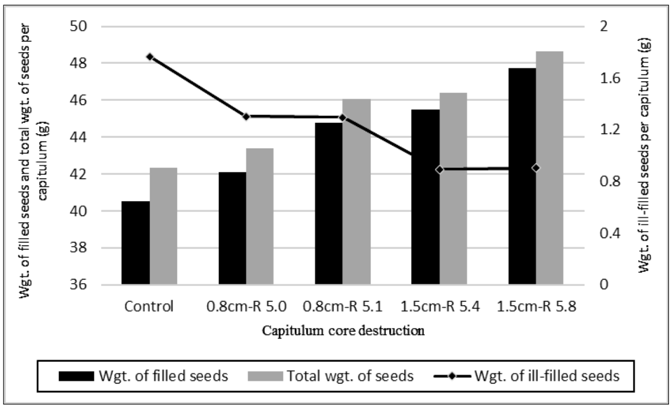

Fig. 9. Effect of capitulum core destruction treatments on the total weight of seeds.

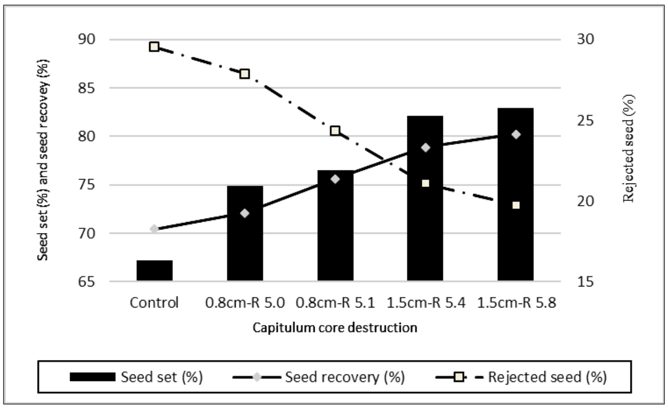

Fig. 11. Effect of capitulum core destruction treatments on the seed set (%), seed recovery (%) and rejected seed (%) in sunflower.

Table 2. Effect of stage and area of capitulum core destruction on seed yield (g) in sunflower var. CO4

Treatments (T)		Seed yield plant^{-1} (g)	Seed yield plot^{-1} (kg)	Computed seed yield ha^{-1} (kg)
T_1	- Control (without core destruction)	42.32	1.79	895
T_2	- 0.8 cm core destruction at R5.0 stage	43.38	1.84	920
T_3	- 0.8 cm core destruction at R5.1 stage	46.08	1.96	980
T_4	- 1.5 cm core destruction at R5.4 stage	46.40	2.03	1015
	- 1.5 cm core destruction at R5.8 stage	48.63	2.16	1080
T_5	Mean	45.36	1.96	978
	SED	0.415	0.024	12.96
	CD (P = 0.05)	0.903	0.052	28.24

(22).The results of the present experiment proved that transfer and accumulation of assimilates in the peripheral and middle region of capitulum from potentially low yielding region of capitulum core *via* capitulum core destruction; have enabled an increase in the number of filled seeds, 100-seed weight and total seed weight per capitulum, resulting in increased seed yield in T_5. The findings were in conformity with in soybean (7), who reported that the raceme removal aided in the reallocation of the available resources from vegetative to reproductive organs which in turn benefitted the reproductive potential of the crop. Thus, the manipulation of source sink ratio, in this case removal of capitulum core improved the crop yield potential, proving the reports of in sunflower (23), Any method to improve the mobilization of photosynthates from the vegetative phase to the capitulum would improve the harvest index and seed production because a significant quantity of biomass is locked up in the vegetative plant parts.

Seed quality attributes

Seed quality is a quintessential trait for agriculture and food security (24). It mainly comprises seed germination and vigour, which are the major contributing characteristics that influence crop establishment. The capitulum core destruction treatment (T_2, T_3, T_4 and T_5) was found to significantly influence the seed germination and vigour (Table 3). The highest seed germination percentage was recorded in T_5 (1.5 cm core destruction at R 5.8) *viz*., 90 and 86% in periphery and middle region respectively, while the lowest value of 86 and 80 % in the peripheral and middle region, respectively was recorded in T_1. With respect to vigour index, T_5 recorded the highest by registering 2875 and 2459 in the resultant seeds of peripheral and middle region, respectively while the lowest was recorded inT_1 *i.e*., 2485 and 1889 in peripheral and middle region, respectively. The same trend was observed with respect to vigour estimates *viz.,* speed of germination, root length, shoot length and dry matter production (Tables 3 and 4).

Table 3. Effect of stages of capitulum development and area of capitulum core destruction on germination percentage, vigour index and dry matter production of the resultant seeds in peripheral, middle and core region in sunflower var. CO 4

Treatments (T)	Germination percentage			Vigour index			Dry matter production (g seedling^{-10})		
	Peri phery	Middle	Core	Peri-phery	Middle	Core	Peri-phery	Middle	Core
T_1- Control (without core destruction)	86 (68.02)	80 (63.43)	70 (56.79)	2485	1889	1542	0.4119	0.3664	0.2967
T_2- 0.8 cm core destruction at R5.0 stage	86 (68.02)	80 (63.43)	70 (56.79)	2520	1949	1636	0.4265	0.3811	0.3002
T_3 - 0.8 cm core destruction at R5.1 stage	86 (68.02)	84 (66.42)	72 (58.05)	2604	2236	1782	0.4374	0.3841	0.3317
T_4- 1.5 cm core destruction at R5.4 stage	90 (71.56)	86 (68.02)	0+(0.5)	2814	2358	0+(0.5)	0.4511	0.4344	0+ (0.5)
T_5- 1.5 cm core destruction at R5.8 stage	90 (71.56)	86 (68.02)	0+(0.5)	2875	2459	0+(0.5)	0.4551	0.4375	0+ (0.5)
SED	1.02	1.12	0.489	31.38	32.35	17.81	0.004	0.006	0.005
CD (P<0.05)	2.16	2.39	1.04	68.36	70.49	38.94	0.009	0.014	0.010

(Figures in parenthesis indicate arc sine values)

Table 4. Effect of stages of capitulum development and area of capitulum core destruction on speed of germination, root length (cm) and shoot length (cm) of the resultant seeds in peripheral, middle and core region in sunflower var. CO 4

Treatments (T)	Speed of germination (cm)			Root length (cm)			Shoot length (cm)		
	Peri-phery	Middle	Core	Peri-phery	Middle	Core	Peri-phery	Middle	Core
T_1 - Control (without core destruction)	6.63	5.38	2.86	16.36	12.42	11.83	12.54	11.19	10.20
T_2 - 0.8 cm core destruction at R5.0 stage	6.75	5.61	3.41	17.11	13.23	12.34	12.19	11.13	11.03
T_3 - 0.8 cm core destruction at R5.1 stage	6.72	5.80	3.74	17.14	13.87	12.65	13.14	12.75	12.10
T_4 - 1.5 cm core destruction at R5.4 stage	6.89	5.92	0+(0.5)	17.55	14.16	0+(0.5)	13.72	13.26	0+(0.5)
T_5 - 1.5 cm core destruction at R5.8 stage	7.10	5.83	0+(0.5)	17.92	14.38	0+(0.5)	14.02	14.21	0+(0.5)
SED	0.112	0.061	0.033	0.135	0.179	0.134	0.182	0.245	0.177
CD (P<0.05)	0.239	0.132	0.070	0.2916	0.390	0.292	0.387	0.533	0.377

The increased seed weight obtained due to better partitioning of assimilates to potential areas of periphery and middle regions enabled by the elimination of competition from seeds in core region. Core destruction in sunflowers enhances seed filling and germination by redistributing assimilates more effectively to developing seeds, ensuring better nutrient availability and promoting uniform growth. This process helps in overcoming the limitations posed by poor seed setting and grain filling, which are common constraints in sunflower production (25). Of all the physical factors, seed weight was highly correlated with the seed germination percentage as reported in various crops such as wheat (26, 27), tobacco (28), *Prunus jenkinsii* (29).

Conclusion

Capitulum core destruction in sunflower has positively enhanced the resource remobilization to the peripheral and the middle region of the capitulum by eliminating competition from the core region, which in turn increased the number of seeds per capitulum, 100 seed weight, as well as total weight of seeds per capitulum, which culminated in higher seed yield. Additionally, the higher seed weight eventually enabled improved seed germination and vigour. Based on the findings, the optimum stage for core destruction was identified as the R5.8 stage, representing 80% flowering of the capitulum area, while the optimal diameter of core destruction was determined to be 1.5 cm. Farmers are recommended to conduct core destruction precisely at the R5.8 stage using tools designed to remove a 1.5 cm core diameter. By adopting this approach, farmers can maximize seed yield and quality by ensuring effective redistribution of assimilates from the non-productive core region to the productive peripheral and middle regions of the capitulum. This technique offers a practical, efficient and scalable solution for enhancing sunflower productivity and optimizing the source-sink ratio in various farming systems.

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Authors' contributions

KN conducted field experiments and collected the data; RU designed the battery operated capitulum core destructor and experiment; TE participated in data analysis; RV and VS designed the figures; VV provided valuable insights during the experiments.

Compliance with Ethical Standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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